27 BRIEFING PAPER

Blockchain Technologies for Commodity Value Chains: The solution for more sustainability?

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Vienna, September 2020

ÖFSE
Austrian Foundation
for Development Research

IMPRINT
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With funding from
Austrian
Development
Cooperation

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List of Abbreviations

3TG	tin, tungsten, tantalum and gold
DL	distributed ledgers
DLTs	distributed ledger technologies
EU	European Union
GVCs	global value chains
NGO	Non-Governmental Organisations

Abstract

With the rising public awareness of poor social and environmental production conditions in many global value chains (GVCs), the pressure for more transparency and traceability is growing. Applications of distributed ledgers (DL) technologies such as blockchains are seen as a key solution in this context. These technologies enable the collection, recording and sharing of the information about physical transactions and related metadata in a tamper-resistant way, without the control of a central actor. This briefing paper presents the basic concepts behind the DL and blockchain technologies and discusses the opportunities and limits of these applications in the context of GVCs. The challenges are due more to power asymmetries in the value chains than to technical issues. Thus, most DL applications could only be tools to bring existing sustainable conditions in GVCs to the fore as long as chain governance and the lack of legal frameworks remain as the main obstacles to extending sustainability in GVCs.

Keywords: Global Value Chains, Governance, Sustainability, Commodities, Blockchain, Distributed Ledgers

1. Introduction

Since the euphoric introduction of cryptocurrencies such as the ‚Bitcoin‘, the term blockchain has become known to a wider public and numerous and applications of these new technologies are reported every day. One field of these applications is linked to more transparency and traceability in global value chains (GVCs). As GVCs and related transactions are increasingly dispersed across multiple firms and geographic spaces, the conditions of procurement and processing have become increasingly opaque. At the same time, information about problematic and illegal practices in GVCs of various consumer goods such as chocolate, coffee, electronic goods or garments has grown in recent years, leading to more awareness by consumers, retailers and producers.

Blockchain technologies – or distributed ledger (DL) technologies more generally – have been promoted as a key solution to support sustainability by increasing transparency and traceability in GVCs. By creating a digital layer upon the physical transactions in a GVC, information on these transactions, on the products and the related metadata – such as production conditions – can be collected, recorded and shared. As this information is gathered and managed without a central authority and stored in tamper-resistant way, it creates a high level of trust in this information. However, blockchain applications in GVCs also face challenges, namely i) the correct linking of the physical and digitals flows in value chains and ii) the impact of governance structures in physical GVCs as well as within blockchain systems on the purposes and management of DL technologies. Both challenges determine the opportunities of these technological solutions to promote sustainability in many GVCs. There is a risk, that these applications remain tools to support primarily existing sustainable conditions in GVCs due to chain governance and the lack of legal frameworks, as long as they are not used as an opportunity to empower smallholder and workers in commodity-producing countries.

The first section of this Briefing Paper illustrates the rising importance of sustainability in GVCs with a focus on agricultural and mineral commodities, and discusses limits of current approaches to ensure and advance supply chain sustainability. The second section explains the basic concepts and terminologies behind DL and blockchain technologies and presents the applications of new technologies for transparency and traceability in commodity value chains. Upon this basis, the challenges of the new technological solutions and the opportunities and limits to support sustainability in GVCs are discussed. The paper concludes that DL systems face some technological barriers, but their impact on promoting and extending sustainability in GVCs is importantly determined by the governance structures within the physical GVCs.

2. The case for transparency and traceability in GVCs

2.1. Changing Nature of GVCs

The production processes in most goods and services sectors and the related financial, legal and administrative activities have substantially changed over the last decades. These processes are increasingly fragmented and dispersed across various actors and geographic spaces. Examples are value chains in textile and apparel, electronic goods, automobiles or processed foods (Ponte/Gereffi/Raj-Reichert 2019). Also, ‘simple’ value chains with few and distinct processing steps and geographical dependencies such as coffee, cocoa or tropical fruits have changed in terms of allocation of tasks, governance, institutional frameworks and price setting (see Tröster et al. 2019 for the case of cocoa; Grabs/Ponte 2019 for the case of coffee).

Transnational corporations (TNCs) exert a dominant role in these GVCs, determining “how financial, material, and human resources are allocated and flow within a chain” (Gereffi 1994: 97). These lead firms manage complex webs of supplier relationships through different modes of governance, ranging from direct ownership of foreign affiliates to contractual relationships and arm’s-length dealings. Gereffi, Humphrey, and Sturgeon (2005) relate the types of governance in different sectors to the complexity of information that needs to be exchanged between the actors to fulfil the different tasks along the chain. This includes, for example, information of global buyers or Original Equipment Manufacturer (OMEs) to their first-tier suppliers on the quality standards of final or intermediary products, as well as specifications on timing and delivery conditions. Even though this standard-setting occurs between lead firms and first-tier suppliers, it is decisive for the governance character of the entire chain. Actors further upstream in the chain have to adjust their activities in accordance with these conventions defined in the central coordination.

Chain governance in complex, fragmented, geographically disperse production processes is therefore possible for lead firms without direct control over the entire value chain as long as the mode of governance ensures that quality criteria and conventions are met. Complete information on all transactions along a value chain and the related conditions of production are not required. It is, for example, not necessary for a coffee roaster to know the detailed origin of coffee beans, as long as the deliveries from an international coffee traders meet the specified quality standards. Thus, the possibility for lead firms to focus on the exchange of specific information with selected nodes in a value chain is an important determinant for the character and structure of cross-border business networks. In other words, the elimination of complete information flows along the entire value chain enables greater fragmentation and organizational distance within the value chains, which, in turn, is a determining factor for the distribution of value-added.

2.2. Sustainability issues in GVCs

The globalization and fragmentation of production processes are a challenge for the environmental, social and economic sustainability within GVCs. Over the last two decades, public awareness has grown that a wide variety of consumer products are potentially produced under poor working and environmental conditions and/or contain raw materials that are grown, harvested or extracted under problematic or illegal circumstances. In particular, campaigns by Non-Governmental Organisations (NGOs), reports by international organizations as well as media coverage have been major drivers to put the spotlight on illegal, exploitative and unsustainable conditions of commodity production, extraction and processing.

Box 1: Rising awareness of sustainability issues in global value chains

The cocoa sector is a prime example of an agricultural commodity-based GVC that is characterized by a large variety of these issues. A British television documentary in 2000 profiled the problem of trafficking and forced child labor in cocoa farming in West African countries. Further, the problem of deforestation, as well as the threats to the livelihood of millions of smallholders in producer countries due to low and volatile prices of cocoa (similarly in coffee and cotton) are have been pointed out (Thorlakson 2018; Huetz-Adams et al. 2016). In the case of cotton, which accounts for almost half of fibres used for clothes, the production uses 2.1 % of arable land globally but accounts for 6 % of the world's pesticides sales, 16 % of insecticide sales and 3% of the world's agricultural water use (Ferrigno 2020). A well-known example of unsustainable practices in the agri-food segment is also the fishery sector, where 90 % of today's global marine fish stocks are fully exploited, overexploited, or depleted (Kituyi/Thomson 2018).

In mineral commodities, campaign slogans such as 'no blood in my cell phone' in the early 2000s drew attention to the war in the Democratic Republic of Congo (DRC) and the connections between conditions of raw material extraction, armed conflicts and daily consumer products (Küblböck/Grohs 2017b). More recently, the trends towards electro-mobility and renewable energy have triggered a debate about minerals such as lithium or cobalt, which are used in batteries and turbines, and the social and environmental circumstances under which they are extracted (Pilgrim/Groneweg/Reckordt 2017). Besides, governments have a decisive role in the minerals and energy sectors via ownership, licensing, taxation and other legal instruments, making the extraction of primary commodities vulnerable to corruption and public mismanagement.

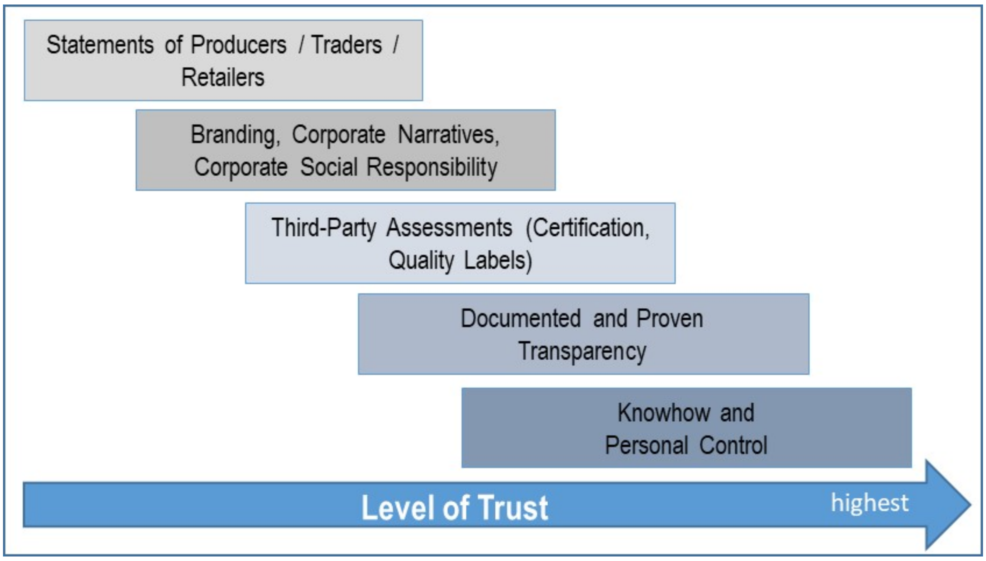
2.3. Responses to unsustainable GVCs

The potential adverse social and environmental conditions in global value chains have triggered responses on different levels and by different actors. For example, international organizations issued guidance on business and human rights or supply chain transparency. The EU and the USA introduced legislation on so-called conflict minerals. And firms, NGOs and other private actors have developed sustainability criteria and certification schemes.

For many lead firms, the growing pressure to assume responsibility for unsustainable practices in their supply chain has led to a contradictory situation: New forms of governance have enabled a restructuring of GVCs, by which lead firms could gain power over the entire chain without direct control over all actors, processes and information. However, the omission of comprehensive information entails that lead firms cannot convincingly guarantee compliance with human, labour or environmental rights along an entire supply chain. Consequently, trust in brands of lead firms, which is an important determinant for price premiums and value creation, has declined in this respect. This could only partly be compensated by Corporate Social Responsibility (CSR) initiatives, which communicate results and steps taken towards sustainable supply chains (see Figure).

Various certification schemes based on voluntary sustainability standards (VSS) have been introduced to document and support the sustainability of agricultural GVCs despite hands-off governance structures. These schemes aim to guarantee that rules, procedures and standards of sustainable production and processing are followed by certain actors (e.g. producers, producer cooperatives). The procedures and standards are typically defined by individual certification schemes. The compliance by producers has to be regularly assessed and confirmed by independent third parties and made visible for consumers via labels. The first certification schemes were created for agricultural products with relatively short value chains and limited processing steps, such as coffee or cocoa. The most important third-party certification schemes for these commodities include Fairtrade International and the recently merged UTZ and Rainforest Alliance. Also, organic certification and labelling have become important in many agricultural GVCs. Numerous commodity-specific certification schemes for cotton, fish and sea food, palm oil, soy, sugar and other commodities have emerged over the last two decades (Lemoud et al. 2018).

Figure 1: Forms of Trust Building with Consumers on Sustainability



Source: Adopted from Düring and Fisbeck (2017: 452)

The individual certification schemes differ in the scope and the strictness of their standards. While certifications may have an impact on selected sustainability issues (Ingram et al. 2018), many studies show that their performance is generally limited (DeFries et al. 2017). Moreover, these schemes cannot address the entirety of sustainability challenges related to multiple factors such as climate change, local socio-economic contexts or strategies of multinational corporations (Huetz-Adams et al. 2016). Further, the auditing itself is prone to misuse due to lax controls and enforcement (Changing Markets 2018), which limits consumers' trust in such certification.

In recent years, private sector initiatives in several commodity sectors have been launched by individual lead firms such as chocolate manufacturers (e.g. Mars, Mondelez, Nestlé) and cocoa grinders/traders (e.g. Barry Callebaut, OLAM, ECOM) or coffee roaster (e.g. Nestlé and Starbucks) and traders (e.g. Neumann, Sucafina, ECOM), or by private sector organizations (e.g. the multi-stakeholder coffee associations Common Code for the Coffee Community – 4C or Global Gap by European retails for fruits, vegetables and other agricultural products). These initiatives target either selected producers or reduce the compliance burdens for producers by simpler verification processes. These private schemes often combine trust in brands and corporate actions by lead firms with increased control of voluntary sustainability standards (see Figure 1).

Also in the case of minerals, awareness of unsustainable extraction and processing has been growing since the early 2000s, largely related to the potential role of mining for financing armed forces during and after the second Congo war (1998-2003). The initial focus was to investigate and break the connection between (illegal) revenues from mineral extraction and the financing of conflict parties in the Democratic Republic of Congo and neighbouring countries (Küblböck/Grohs 2017a). As a result, international normative frameworks, standards and principles, and eventually legally binding regulations have been introduced, which lead to certification and traceability schemes in the region (Küblböck/Grohs 2017a; Kickler et al. 2018).

A central element of the regulatory framework on minerals is the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas published in 2011. It instructs companies on how to ensure responsible sourcing of minerals (OECD 2016). In alignment with this guidance, the USA has introduced legally binding standards of the Dodd Frank Act in 2012 that obliges listed companies in the USA to disclose if their products contain tin, tungsten, tantalum and gold (3TG) from the DR Congo or an adjoining country. The EU published the Conflict Minerals Regulation for the same 3TG minerals in 2017, that will enter into full force in 2021. It includes due diligence requirements only for importers of raw materials and smelter products from all conflict-affected and high-risk-areas worldwide above certain thresholds. The list of conflict areas has to be defined by the end of 2020 (Küblböck/Grohs 2017a).

In recent years, numerous organizations and actors have created sustainability standards and related certification schemes on minerals, many of which can be understood as tools for companies fulfil their due diligence and legal obligations. The individual schemes differ concerning the social, environmental and economic grievances addressed, minerals, actors, and supply chain segments covered and the certification and verification processes. One particular challenge is to ensure correct tracing back to the source of the respective minerals, that is, to the individual mines (Kickler/Franken 2017; Küblböck/Grohs 2017b for more details).

Very similar to agricultural goods, the confidence of consumers and public authorities on the accuracy of the standards and their effects on sustainability depends on the reliability of the certification and auditing processes. In the case of conflict minerals, these can be particularly challenging, as the auditing has to take place in high-risk areas, and as minerals from different origins are aggregated, smelted and further processed. As the supply of minerals and metals is nevertheless expected to rise with the growing demand for electro-mobility (in particular cobalt and lithium) and renewable energies (copper), the need to ensure sustainable supply is looming.

Overall, certification schemes and solutions for more traceability – driven by NGO, private sector initiative or legal requirements – have increased the availability of information on production and processing conditions, and corresponding labels have made it easier for buyers and customers to obtain information. However, this information depends on third parties acting as intermediaries and on the accuracy with which this data is assessed, controlled and published. Therefore, new solutions based on ‘distributed ledger technologies’ are currently promoted to overcome the deficits of third-party assessments, by promising documented and objective transparency and traceability. Eventually, such applications should establish end-to-end visibility of production processes allow value chain actors and final consumers to control information (Figure).

3. Technology for transparency and traceability in GVCs

The basic idea to use technological solutions to document sustainability in value chains is to provide validated information on the products, its components and processed raw materials (transparency). This information can contain data on the origin and use of raw materials throughout the production processes and transactions (traceability) and include metadata on the circumstances of commodity extraction as well as on processing. In particular, ‘distributed ledger’ or ‘blockchain’ technologies are perceived as an ideal approach to facilitate the creation, validation, recording, storing and sharing of the relevant information among value chain actors, without the need for a central authority or institution. This record-keeping is the basis to exchange ownership without intermediation, but it can be used to create a distributed, tamper-resistant and transparent record of almost anything. Thus, it can be a tool to increase transparency within value chains and provide reliable information on products and processes to actors outside the value chain. Moreover, these technologies can simplify and facilitate transactions along the value chain.

Even though the number and variety of use cases of DLTs have been evolving dynamically in recent years, there are still many obstacles for these technologies in the context of GVCs and their governance structures. Before these issues are discussed in detail, basic concepts and terminologies as well as examples for their applications in GVCs are introduced.

3.1. Basic concepts and terminologies

The most prominent example of an application of blockchain technology is the Bitcoin cryptocurrency network, based on the concept of Nakamoto (2008). The technology behind the Bitcoin enables *disintermediation* in the transfer of the cryptocurrency from one network member to another. These transactions can be performed among multiple actors without third-party mediators or control of a central authority, which would keep information in separate, centralized databases. Instead, the application of software to store and manage data in a distributed system among the members of a network – while keeping the integrity of these data – provides the possibility to transfer assets without intermediation. This decentralised recording of transactions and information without central coordination is also the bases for transparency and traceability in supply chains, as network members can have access to the full history of transactions registered in the database.

In a centralised system, third party institutions ensure the validity of transactions through their intermediation services, in which they contract, clear, settle and record transactions with centralised databases (Tripoli/Schmidhuber 2018: 3). Examples are banks acting as intermediaries in financial transactions or notaries and public authorities confirming ownership and transfers of real estate. But also frequent online activities, such as the correct delivery of e-mails or the publication of postings for certain friends in social networks, depend on third-party service providers (Crosby et al. 2016: 8). Difficulties in such centralized systems are the dependence on central authority to perform transactions correctly and to handle and store information securely. In addition, transparency is limited, as information is controlled and managed by specific actors and not available for all actors.

The pragmatic solution to eliminate the third party and centralised control in transactions is to make everyone the third party. In other words, every participant of a network keeps a copy of the record containing the history of all past transactions and relevant information, and the participants control collectively the access and the evolution of this record. In such a way, ownership of an asset, such as the bitcoin, is determined by the log of all past transactions. Distributed systems incorporate three key features: the *distributed nature of the records*, *cryptographic mechanisms* to keep records immutable and secure and the *consensus mechanism* to update the records (see Brakeville/Perepa 2019; Drescher 2017; Voshmgir et al. 2019 for details).

The first feature is the distribution and storage of information across multiple computing devices. Such a log of transactions and information is often associated with business ledgers, which has led to the term *“distributed ledgers”* for data records on distributed databases. The term, *“blockchain”* describes a particular type of data structure used in distributed ledgers, in which information is bundled in so-called ‘blocks’, which are then linked to each other in a digital ‘chain’. Blockchains also have an append-only data structure, meaning that new data entries can only be added to the chain of past blocks. In most applications, this chaining of blocked transactions is desirable as it allows past transactions to be displayed in a traceable manner. Therefore, the term blockchain has become an umbrella term referring to the data structure, the applied technologies and algorithms, or the distributed system as a whole.

The challenge in distributed ledger systems is to ensure the integrity of data, in particular when new information is added to the ledger. This means that data are complete and correct, they change in the intended way and incorporate no logic errors, and access is only given to permitted users. This integrity must be ensured even in the case of an unlimited number of network peers, whose reliability and trustworthiness is unknown. Thus, so-called *Distributed Ledger Technologies* (DLTs) enable the creation, validation, recording, storing and sharing of the relevant transaction information within a network. Depending on the purpose and the rules of the application, the DLTs combines technologies and know-how from various disciplines such as cryptography, software engineering, finance, economics, philosophy, law, and others (Walch 2017: 725).

The second feature of distributed ledger systems is the use of *cryptography* that ensures the immutability and security of data records.[1] This function is based on so-called hash functions that create digital fingerprints (hashes). Such a hash is created for each data entry in combination with a timestamp and the hashes of past, interlinked data entries or blocks. Thereby, all data entries are linked to one another and manipulation of past data entries would also change the most current hash created. Such a change could be easily detected by any user by comparing hash values. Thus, the record of data can be saved change-sensitive, meaning that DLs can be described as ‘tamper-evident’ or ‘tamper-resistant’ as changes in the data are easily detectable.[2] This high level of immutability and security of data entries is essential for the DL systems, as the record of past transactions determines the ownership of assets, and it creates trust in the quality of data records without a central authority or institution.

The third feature in DL system is the *consensus mechanism*, which ensures collaborative control over new entries to the record of transactions and events, even if the network participants act independently and with different motivations and objectives. For this purpose, consensus protocols include algorithms with a set of rules that prevent any interference on the integrity of the data and enable an agreement among all participants on a valid status of the distributed ledgers. There are various possibilities to achieve these aims, depending on the character and the purpose of the network. Consensus mechanisms are generally more complex when the number of network members is high, the participants are unknown, and when malicious users are likely. Thus, the consensus mechanism is adjusted to the purpose and type of DL systems and depends on the requirements for performance, scalability, consistency, governance, or failure redundancy (Seibold/Samman 2016).

The different types of consensus mechanisms are loosely linked to the different variants of DL systems, which differ by the access to a network (*Open or Closed*) and by the permissions granted to the network members. These permissions refer to the possibilities to ‘*Read’* (who can access the ledger and see the content, *Public or Private*), *‘Write’* and *‘Commit’* (who can generate transactions and who can update the state of the ledger – *Permissionless or Permissioned*) (Hileman/Rauchs 2017: 20). Among the variety of possible combinations, the majority of DLT use-cases apply the following two types of permission set-ups:

(i) *Open – Public – Permissionless:* The access to these DL systems is open for everyone and all the participants can read and write (make) transactions. Further, it is permissionless for every participant to update the state of the ledger. Examples are the cryptocurrencies Bitcoin and Ethereum.

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[1] Cryptography is also used to manage access to distributed data, identify users and protect user accounts via asymmetric cryptography through private and public keys. Moreover, the consensus mechanism can use hash puzzles as a way to ensure that updates to the blockchain are correct.

[2] DL systems are often described as “tamper-free”, but the DLT design can allow revisions of past data under specific circumstances if enough nodes agree with such changes (Hileman/Rauchs 2017: 17)

(ii) *Closed – Private – Permissioned:* The access to these types of DL systems is restricted to authorized participants, the rules to read are restricted and the possibilities to write and commit are permissioned. A prominent example is Hyperledger, a DLT system that is used for networks of companies (consortium) within a supply chain.

The consensus mechanisms often build on incentives for those members that have the interest to ensure that updates to the blockchain maintain a coherent set of distributed ledgers among the network members. In the Bitcoin network, which is an open, public and permissionless system, new blocks are added by the member that solves a so-called hash-puzzle that requires computational work. This proof-of-work mechanism is also known as 'mining' as the fastest to solve the puzzle is rewarded with bitcoins if the other members agree with the solution (Hileman/Rauchs 2017). This consensus mechanism is energy and time intensive, but it ensures that the nodes behave honestly and cooperatively (Drescher 2017).

In close DL systems, the consensus mechanisms are less burdensome, as all participants are known and authorized and they are often "extrinsically incentivized" to behave correctly through legal contracts or operational targets (Seibold/Samman 2016: 12). Therefore, consensus mechanisms can be simplified, but it includes rules by which transactions and data are validated and processed without an intermediator (Tripoli/Schmidhuber 2018). Nevertheless, single members of private networks can have superior permissions to read, write and commit to the ledger than other network members.

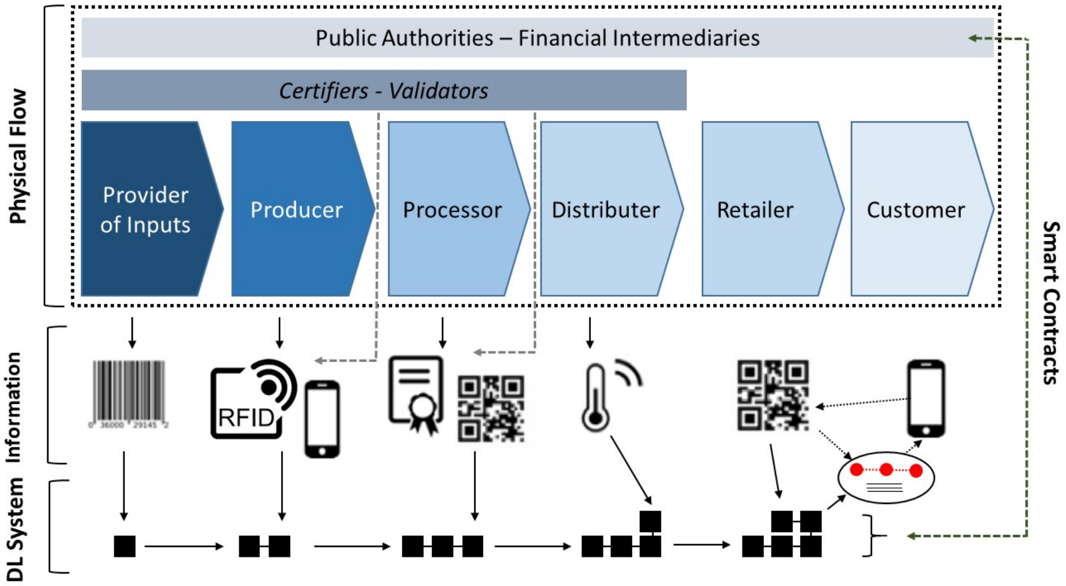
In DL applications for supply chains, the consensus protocol is designed to take up underlying specifications of the physical transactions and the protocol can be extended through *smart contracts*. The software combines the validation and update of the blockchain with the execution of contractual processes (e.g. payments once a good has arrived in a warehouse). Thereby, DL system can integrate the performance, monitoring and enforcement of contractual agreements without a central authority or human involvement. Thus, DLTs and smart contracts enable more efficiency in supply chains (ibid.).

3.2. Applications of DLTs in commodity value chains

The applications of DLTs in commodity value chains can be understood as a digital layer upon the physical structure of the supply chain (see Figure 2). The basic steps of physical transactions, e.g. from growing coffee to roasted coffee beans in a supermarket shelf, and the exchange of ownership remain unchanged. Information on these transactions, as well as metadata around these transactions and the products, are collected and saved on a DL system. This sequential addition of information matches with the sequential characteristics of physical transactions. Digital carriers and other technologies link the physical goods to digital information and can add further information.

The actors in these value chains are typically not anonymous, meaning that DL systems in commodity value chains are closed, private and permissioned. The rules to read, write and commit often reflect governance structures in the underlying value chain, as many DL systems are initiated and run on behalf of lead firms that have a vital interest in creating transparency in (parts of) the value chains. End-users outside the value chain can only see the selected information necessary for transparency, while sensitive data are protected. Thus, DLTs in commodity value chain are not used to transfer ownership of a (digital) asset as in cryptocurrencies, but rather to reliably record information on and around physical transactions without the control of central parties.

Figure 2: Physical and Digital Layers in a Commodity Value Chain



Source: adapted from Kamilaris, Fonts and Prenafeta-Boldú (2019)

The availability of information along an entire value chain can be used for various purposes. Most DLT applications create this distributed pool of information to increase the transparency of production and processing and to enable the traceability of transactions throughout the value chain (for an overview on application in agricultural and food supply chains, see Kamilaris/Fonts/Prenafeta-Boldú 2019). The lack of a central authority to gather, store, publish and potentially alter these data gives this information a higher level of trust. In addition, the DLTs can enhance the performance of physical and financial transactions when smart contracts are integrated (Tripoli/Schmidhuber 2018).

DLTs in commodity value chains face, however, two major challenges. Firstly, the digital layer needs to be connected to the physical layer of a value chain, so that information that flows into the DL is correct from the outset. While DLTs enable a tamper-resistant storage of information through blockchains and cryptography within the DL system, the quality and reliability of the stored information depends on the input flowing into the DL and cannot be enforced by the DLT themselves. To reduce this risk of the 'first mile', the commodities must be identifiable throughout the transformation processes along the value chains. Data carriers such as barcodes, RFID chips or QR codes attached to the commodities and products link the physical to the digital flows (King/Haslhofer/Schlarb 2018) and technologies such as GPS tracking or digital sensors and the use of software in the field of machine learning, artificial intelligence and 'Internet of Things' can enhance this linking (Voshmgir et al. 2019). These technologies enable the recording and analysis of information, but they require a certain level of technological capacities and infrastructure, and potential manipulations cannot be entirely excluded by the DLTs itself (Wüst/Gervais 2018).

Further, the actors in the value chain must be given a digital identity and use the cryptographic public and private keys when sending data to the DL (Tripoli/Schmidhuber 2018), but additional technological solutions are possible. And information on ecological and social conditions during production, harvesting and processing of commodities can be fed into the DL system, but the correctness still relies largely on the verification and certification by third parties that control the conditions, very similar to existing certification schemes (King/Haslhofer/Schlarb 2018).

A second challenge in DL system in commodity value chains refers to the type and scope of the information collected and the access to this full information in the DL as well as the ability to analyse and utilized these data. The type of information that is included in a DL system depends on the objective of the DL. For instance, DL systems that aim for support of smallholders might include data on prices paid to commodity producers, while other DL systems that simply trace products to their origin might include GPS data. Further, DL systems that focus on food safety might include data on the temperatures along the entire value chain from processing facilities, transport vehicles, warehouses and cooling counters in supermarkets or laboratory testing results (Tripoli/Schmidhuber 2018).

Contrary to the anonymous blockchain networks such as Bitcoin, in which full transparency on transactions and information is necessary, the availability of all information is not desirable for all companies in a value chain (Wüst/Gervais 2018). Thus, specific network members in value chains should have specific permissions that are relevant for the functioning of the DL system and for more efficiency in transactions, but other information should be protected. For instance, a DL system with different suppliers can keep specific information secret from the competitors. DL systems might also give permissions to third parties, such as public authorities, in case of contaminations in foods. The DLT rules must include permissions that provide transparency while respecting sensible and private information. This requires appropriate structures and transparency in the development and operations of such closed DLTs (Accenture 2019: 17). As many DLT applications are currently initiated by lead firms in commodity value chains, permission in these systems can potentially mirror the interests and strategies of the corporations and these actors have the capacities to analyse the available data for these purposes.

3.3. Selected examples of DLTs in commodity value chains

Over the years, a large variety of applications for DLTs have been initiated in value chains of agricultural commodities and foods as well as minerals. Beyond better traceability for food safety[3] and more efficient logistics in international trade[4], the trend has been driven by the request for more transparency and sustainability as well as by legal requirements in the case of conflict minerals. On the one hand, many projects have been developed by third parties outside the value chains, in many cases with the objective to promote smallholders and/or better ecological and social conditions in production and processing. On the one hand, lead firms in the agriculture value chains such as large retailers, food processors and international commodity traders or mining companies in extractive value chains are promoting blockchain-based applications (Addison et al. 2019). In particular, the *Hyperledger* system as an open source project under the Linux Foundation has been introduced as the platform that allows firms to develop customize DLTs (Hyperledger 2020).

First examples of the blockchain technologies were realised for wild-caught fish for which processing steps are limited. Projects by the WWF (Visser/Hanich 2017) or the UK-based company *Provenance* as third party actors outside the value chain aim to combat illegal fishing methods and overfishing tuna and other fish. For this purpose, these applications trace the fish from fishermen to the final selling point. Information on the location and methods of fishing, trading and processing is fed into the DL by the fisherman and the processors, for instance via SMS or mobile applications. This requires, however, that these actors and their social and environmental working conditions are verified by local NGOs or other certification schemes. Finally, the flow of information and metadata is linked to the real fish through unique identifiers attached to the fish as RFID tags and QR Codes (Provenance 2016). Further applications on the traceability of seafood and other products have been developed to improve food safety,

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[3] See the example the DL system by Walmart (Hyperledger 2019).

[4] See the example the DL system by Maersk (TradeLens 2020).

as DLTs allow for the control of compliance to public standards and the fast and simple traceability in the case of spoiled foods (FAO 2020). DLT applications in the agriculture commodities often refer to products that are typically associated with adverse effects in their production. This includes, for instance, blockchain-based traceability systems on beef and soybeans from South America, which are often linked to deforestation (Accenture 2019).

The coffee sector, in which 25 million smallholders in the Global South grow coffee beans that are traded, roasted and marketed globally by few global coffee traders and roasters (Grabs/Ponte 2019; Tröster 2015), is often associated with economic and social unstainable conditions for coffee farmers. Lead firms in the coffee value have recently initiated blockchain solutions. These document the trace of so-called 'single origin coffees', which are roasted coffees from a single farmer or cooperative. For instance, Jacobs Douwe Egberts (JDE) and J.M. Smucker as leading roaster and Volcafe and Sucafina as leading coffee traders have engaged with other major companies in the sector in the project *Farmer Connect*[5]. The platform allows coffee consumers to receive information about the different stages of processing from dry mills to warehouses and roasting facilities and encourages customers to support social and ecological projects in the origin region. Up to now, it includes only coffee from Colombia and coffees that are certified by UTZ and Rainforest Alliance. The leading coffee roaster Nestlé has also announced a blockchain application for premium coffees in Sweden, originating in Brazil, Ruanda and Colombia, and in cooperation with Rainforest Alliance (Nestlé 2020).

Both coffee sector projects use *IBM's Food Trust* platform based on *Hyperledger Fabric*. The network members, including coffee farmers, receive a digital identity, which enables them to send identifiable data to the distributed ledger. In the mentioned examples, established networks with coffee farmers facilitate this process further. The validation of the new, encrypted information and the update of the distributed ledger, while maintaining its integrity, relies on 'trust anchors' (IBM 2019). The food trust platform uses a simpler consensus mechanism (Practical Byzantine Fault Tolerance – PBFT) that is performed only by selected members, which hold a full copy of the ledger. This simplifies the participation of smallholders with low technological capacities, but potentially leaves the organization and management of the platforms with lead firms. Even though the basic set-up of the IBM platform ensures that data are encrypted and data owners must explicitly grant other users access to their data, these rules and permissions can be adjusted within the individual application.

Within the minerals sector, the structural difference between large-scale extractions and artisanal mining is also reflected in the development of DLT applications. Early applications have focused on the traceability of diamonds (see Cartier/Ali/Krzemnicki (2018) on Everledger and DeBeer's GemFair project). However, more recent examples are linked to mineral production in the DR Congo and in particular to its large reserves of cobalt, which is not part of the 3TG conflict minerals regulation, but associated with child labour and dangerous working conditions in artisanal mining. As demand is rising for batteries in electric vehicle and other electronic products, global battery and automobile producers have started initiatives on the traceability of these minerals. For example, the mining company and commodity trader Glencore has entered into a consortium with multiple carmakers and battery producers (Ledger Insights 2019) and announced a cooperation with Tesla (Shead 2020) in which cobalt supplies from DR Congo are traceable from mines over smelters up to the final product through a DL system. The blockchain applications should ensure that the origin of their cobalt can be traced back to specific mining sites under the responsibility of a transnational mining company and thereby exclude cobalt extracted by artisanal miners under unsustainable conditions.

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[5] See https://www.farmerconnect.com/

On the other side, other DLT applications focus on the integration of artisanal mining into legal supply flows. As these sources are closely linked to conflict minerals regulations in the US and the EU, the origins of these minerals are important to determine its legality, but also to inform about working conditions and improve them. Examples are a blockchain solution for the tantalum value chain from Ruanda by *Circulor* (Hyperledger 2018) or *MineSpider* (Williams 2018). The challenge in these value chains is the ‘onboarding’ – the certainty that the minerals included in the blockchain come from the respective mining site. In the *Circulor* application, the registered artisanal miners are identified by face scans and ID cards and linked to bags of ores with a QR code and a GPS tracking system. The tagging of bags corresponds to earlier initiatives on the traceability of minerals from conflict regions without DL systems, such as the Tin Supply Chain Initiative (iTSCi) (see Kickler/Franken 2017; Küblböck/Grohs 2017a). In both systems, with and without blockchains, the risk remains that bags contain minerals from other mines. This could be overcome with analytical fingerprints that identify the origin of minerals through geochemical features (Schütte 2018), which is however costly and applicable only for selected minerals. Moreover, smelting is often identified as a critical processing step for the traceability of minerals as minerals from different mining locations are combined. One approach is to treat conflict-free minerals similar to renewable energy, which the end-user receives in a mix with energy from other sources, but still pays a higher price to the renewables producer (Herranz 2018).

4. Opportunities and Limits of DLTs in GVCs

The systems based on distributed ledgers or blockchains provide the basis for innovative approaches in many sectors and various purposes. The most radical changes refer to the potential elimination of intermediation for the transfers of ownership of digital goods and services, for instance in finance. In value chains of commodities and other products, the innovation from DL systems consists in the creation of digital layers on top of the physical transaction, in which information on the transactions and metadata as well as production and processing conditions can be collected, stored and used without a central actor or authority. DL systems have therefore a high degree of self-organisation.

The DL technologies allow for a simplified data collection along an entire value chain in the first place as all participants in the value chain are part of the digital layer, which overcomes data silos and connects all value chain actors throughout the different processing steps. Once this comprehensive information is available, these data can provide transparency on the activities along fragmented GVCs. In the case of sustainability issues in commodity value chains, the information on value chain transactions enables end-to-end traceability of raw material inputs through manufactured goods processing and consumption, and collected metadata make the conditions in production and processing visible. The tamper-resistant nature of the DL systems increases the reliability of this information and can contribute to a higher level of trust of end-users in the production and processing of raw materials into final goods.

DL systems can also lead to higher incomes for upstream actors in sustainable value chains. On the one side, the processing of transactions can be made more efficient and less costly through smart contracts and through data analysis (Voshmgir et al. 2019). On the other side, DL technologies allow to collect, store and control data on physical transaction among different actors with a high level of reliability. This can strengthen existing sustainable production and processing, by documenting these transactions and related metadata in a traceable and transparent way. The tamper-resistant structure without the control of a central authority enables trust-building by final consumers and could increase the willingness to pay higher premiums for documented sustainability. In combination with more efficient transaction processing and lower transaction costs, incomes of upstream actors could be elevated. This can incentivise other producers and processors to apply more sustainable practices as the DL systems give upstream actors greater visibility and appreciation in the value chain. In particular, DL applications, which aim to empower small farmers by bypassing middlemen and lead companies, can use these functions.

Even though, DL systems provide numerous opportunities for applications in global commodity value chains due to the combination of DL systems with other technologies in the context of artificial intelligence, machine learning or big data analysis (Voshmgir et al. 2019), there remain technological boundaries due to performance, speed, scalability or confidentiality of DL systems, which are often mutually exclusive conditions (Hileman/Rauchs 2017). Moreover, DL systems in commodity value chains face additional challenges due to i) the link between the physical and the digital layers and ii) the governance within DL systems and in physical value chains. In combination, these two challenges determine the opportunities and limits of DL systems for sustainability in value chains

First, the reliability of information depends on the requirement that the input must be correct from the outset. DL systems can integrate identity checks and internal control systems such as mass-balance checks and technical tools such as GPS tracking, digital sensors or RFID chips to link physical goods with the digital layer more directly. These technical solutions cannot entirely eliminate the risks that raw materials from different sources will be mixed or replaced and their application depend on the technical capacities and available infrastructure. This is a limiting factor in particular for smallholders in low-income countries as it is technically and financially more burdensome to apply these systems. Further, the metadata on production and processing conditions still depend on the verification and certification by third parties, and therefore on the quality of these certification schemes.

In order to reduce the risk of false information intake, many existing DL systems for sustainability in commodity value chains focus on parts of commodity sectors and value chains, which already have a relatively high degree of sustainability and transparency. These often represent a niche market in a sector and the various actors are already known. For instance, current DL applications in coffee value chains increase the visibility of existing supply transaction in ‘single origin coffees’ between farmer organisations in Colombia, traders and roasters. The ‘onboarding’ problem of bringing coffee smallholders into the DL system is minimized by cooperation with the national farmers’ associations and coffee farmer cooperatives in Colombia as well as with certification schemes on sustainability, such as Rainforest Alliance and UTZ. This raises the question of the additional benefits of DL applications when relations among trusted actors are already established (Wüst/Gervais 2018). In such cases, DL systems provide only an additional option to present more reliable data on sustainability without changing the production conditions directly or enable inclusion and empowerment of smallholders (Voshmgir et al. 2019).

Secondly, DL systems have to be developed and managed. The development of DL system can be initiated by third parties, while the systems are applied by value chain actors. Alternatively, one or more value chain actors can initiate and run the application with all other chain actors. In any case, the DL systems are customized for a specific purpose in a given value chain and the permissions to read, write and commit information need to be defined and organized among the network members. This includes decisions on what information is collected, who agrees on updates to the DL, and what is published within and outside the value chain.

In DL system established by lead firms, the governance within the DL system often mirrors power asymmetries in the physical value chains. Although the elimination of data control by a particular entity is a key feature of DL systems and DL platforms allow the management of sensitive data by individual network members, the specific purposes of DL systems are often defined by the lead firms and determine what data are included. In particular, strategic and sensitive information such as prices or margins that could influence competition and bargaining power between network members are typically excluded. However, such information is highly relevant with regard to economic sustainability for smallholder and their empowerment. Many DL systems established by lead firms are not a tool to change power relations within certain value chains, even though they entail more transparency and greater visibility for the chain actors.

The setup and the closed nature of DL systems in GVCs can even increase dependencies of upstream actors, in particular if they have fewer permissions in the DL applications due to technical or financial limits. In addition, unequal capabilities to analyse value chain data can further strengthen existing power asymmetries. Even if all network members have the same access to the information stored on the DL, dominant downstream actors can use the information with their data analysis capacities to improve their business strategies and the governance with the value chains. In contrast, smaller actors often lack the ability to analyse the data on the entire value chain and to use them for their strategic purposes, in particular, when the collected data exclude relevant information. Therefore, transparency on the configurations and management of the DL systems are important factors to increase the quality and the substance of the data published outside the value chain.

The governance and power asymmetries in underlying physical value chains also constraints the role of DL systems in promoting sustainable practices in a commodity sector. These asymmetries are driven by lead firm strategies to fragment processing steps and to outsource activities with lower value-added to other chain actors. The key to govern these fragmented value chains are specific information that enables continuous supply flows with predefined quality standards. Thus, existing supply chain relations along the entire chain can be loose, as governance by lead firms is possible without complete information on production and processing conditions in the single segments. Greater transparency of transactions and metadata could even affect lead firms' power and ultimately the distribution of value-added. Therefore, closer cooperation between all actors along a value chain in a DL system with complete information on production conditions is generally not part of lead firm strategies in many value chains, which is also a factor for the relatively low levels of sustainable production in most value chains. In such cases, legal obligations for lead firms to trace material inputs and the related productions and processing practices through DLTs could be used to promote sustainability in GVCs.

5. Conclusions

Overall, DL applications have the potential to improve sustainability in value chains of agricultural and mineral commodities. The underlying architecture allows the value chain actors to collect, manage and store information on transactions and metadata without a third party in a digital layer upon the physical value chain and increases the transparency and the traceability in these value chains. However, the DL applications depend on the existence of physical transactions with sustainable conditions for smallholder, artisanal miners and workers, and DL systems are primarily tools to provide reliable information on these processes along the value chains. The creation of sustainable production and processing is therefore the necessary pre-condition for DL systems to support and enhance sustainability.

Apart from the technical challenges to link the physical and the digital layers, the potential of DL systems to promote sustainability in GVCs depends on power asymmetries in GVCs and the implications for the purpose and management of DL applications. The governance of GVCs by lead firms has, on the one hand, an impact on the extend of the sustainable practices in commodity sectors. On the other hand, lead firms have the technological and financial capacities to develop and manage DLTs and thereby determine the purpose and the use of collected data, which can even increase dependencies and unequal power relations within GVCs.

If technical solutions such as DL systems are to foster more sustainability in GVCs of agricultural and mineral commodities, value chains actors and policy makers should focus on the opportunities of these application to empower smallholders and workers through more visibility and appreciation in global value chains, and through the self-organisational capacities of the technologies when DL systems are developed and managed (Voshmgir et al. 2019). In this way, DLTs can also contribute to the dissemination of sustainable processes. This also implies to challenge existing GVC governance structures, e.g. through alternative marketing routes such as direct marketing with processors and end-users in consumer countries in combination with DLTs.

Finally, DLTs could play an important role in the implementation of mandatory due diligence processes with regard to human rights and environmental issues in supply chains, as currently discussed in the EU. As the examples of regulations in the mineral sectors show, that the implementation of legal requirements depends to a large extent on the possibility to trace the production processes using suitable tools. Properly applied, DLTs can provide reliable data on sustainable practices and empower upstream actors when lead firms in the EU need to document production and processing conditions along the entire global value chains.

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