DIGITAL SOLUTIONS FOR SUSTAINABLE COMMODITY VALUE CHAINS

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INTRODUCTION[1]

With the rising public awareness of poor social and environmental conditions in many global value chains (GVCs), the pressure for more transparency and traceability in supply chains is growing. However, as GVCs and related transactions are increasingly dispersed across multiple firms and geographic spaces, the conditions of procurement and processing have become increasingly opaque. In this context, blockchain technologies – or distributed ledger (DL) technologies more generally – have been promoted as a key solution to foster sustainability by increasing transparency and traceability in GVCs.

The term *'blockchain'* has become known to a wider public with the introduction of the cryptocurrency 'Bitcoin'. Numerous innovative applications of these new technologies are reported every day. In the case of GVCs, this technology creates a digital layer upon the physical transactions, in which 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 information with a high level of trust for consumers. But blockchain applications in GVCs also face challenges and constraints. These challenges are due more to power asymmetries in the physical value chains than to technical issues. Therefore, DL applications can only be tools to bring existing sustainable conditions in GVCs to the fore as long as chain governance, missing empowerment of smallholders and works and the lack of legal frameworks remain the main obstacles to extending sustainability in GVCs. Development policies and cooperation should use these technical solutions as a tool to promote sustainable processes in GVCs through the capacities of DL applications to empower smallholders and workers in commodity producing countries.

The next section of this article 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, as well as entry points for development policies in this context are discussed.

SUSTAINABILITY ISSUES IN GVCS

Over the last decades, the production processes in most goods and services sectors have been 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 et al. 2019). This includes also changes to 'simple' value chains with few and distinct processing steps and geographical dependencies such as coffee, cocoa or tropical fruits (see Tröster et al. 2019 for the case of cocoa).

Transnational Corporations (TNCs) exert a dominant role in these GVCs. 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. However, chain governance in complex, fragmented, geographically disperse production processes is possible for lead firms without direct control over the entire value chain and complete information on all transactions along a value chain, as long as the mode of governance ensures that quality criteria and conventions are met (Gereffi et al. 2005). In other words, the elimination of complete information flows along the entire value chain enables greater fragmentation and organizational distance within a value chain, which, in turn, is a determining factor for the distribution of value-added.

Globalization and fragmentation of production processes are however 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 NGOs (Non-Governmental Organisations), 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.

This has 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. Firms, NGOs and other private actors have developed sustainability criteria and certification schemes. In particular, lead firms are confronted with increasing pressure to assure sustainable practices in their supply chain. This 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 despite Corporate Social Responsibility (CSR) initiatives in this respect.

As a possible solution, various certification schemes based on voluntary sustainability standards (VSS) have been introduced to document and support the sustainability of agricultural GVCs. These schemes aim to guarantee that rules, procedures and standards of sustainable production and processing are followed by producers. These procedures and standards are typically defined by individual certification schemes and differ in scope and strictness. Producer compliance has to be regularly assessed and confirmed by independent third parties and made visible for consumers via labels. These certification schemes are particularly used for agricultural commodities and many schemes have emerged over the last two decades (Lemoud et al. 2018).

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 certifications.

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) and the potential connection between (illegal) revenues from mineral extraction and the financing of conflict parties in the region (Küblböck/Grohs 2017a). As a result, international normative frameworks, standards and principles, and eventually legally binding regulations have been introduced. 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 (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 United States to disclose if their products contain tin, tungsten, tantalum and gold (3TG) from the DR Congo or an adjoining country.[2] 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 to fulfil their due diligence and legal obligations. 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). The auditing in these value chains can be particularly challenging, as it has to take place in high-risk areas, and as minerals from different origins are aggregated, smelted and further processed.

This poses a limitation with respect to the confidence of consumers and public authorities on the reliability of the certification and auditing processes.

Overall, certification schemes and solutions for more traceability 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.

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) throughout the single production processes and transactions (traceability), as well as to include metadata on the circumstances of commodity extraction and processing. In particular, 'distributed ledger' or 'blockchain' technologies are perceived as an ideal approach to facilitate the creation, validation, recording, storing and sharing of such information among value chain actors, without the need for a central authority or institution.

These technologies create distributed, tamper-resistant and transparent records, which can be used for different purposes and in particular for the exchange of ownership without intermediation, as is applied in cryptocurrencies. In the case of GVCs, this record of information has the purpose to collect and store these data among specified actors along a value chain. The data can be utilized to document, trace back and publish transaction data as well as to simplify and facilitate transactions along the value chain.

BASIC CONCEPTS AND TERMINOLOGIES

Commonly information around transactions are handled in centralised systems, in which third party institutions ensure the validity of transactions as they contract, clear, settle and record transactions with centralized 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. Also emails or postings in social networks are based on centralized systems (Crosby 2016: 8). However, these systems depend on a central authority to perform transactions correctly and to handle and store information securely, but provide limited transparency.

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. 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 Drescher 2017; Voshmgir et al. 2019 for details).

The first feature is the distribution and storage of information across multiple computing devices in *"distributed ledgers"*, which are associated to a log of transaction in a business ledger. 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'. [3] The challenge in distributed ledger systems is to ensure that data are complete and correct, change in the intended way and incorporate no logic errors, and that access is permitted (integrity of data). Depending on the network of actors, this integrity must be given even in the case of an unlimited number of network peers, whose reliability and trustworthiness is unknown. Thus, so-called *Distributed Ledger Technologies* (DLTs) combine technologies and know-how from various disciplines to enable the creation, validation, recording, storing and sharing of the relevant transaction information within a network (Walch 2017: 725).

The second feature of distributed ledger systems is the use of *cryptography* that ensures the immutability and security of data records.[4] With so called hash functions, data entries or blocks can be interlinked and changes to the data 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.[5] This high level of immutability and security of data entries is essential for the DL systems, as 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. There are various possibilities to achieve these aims, depending on the character and the purpose of the network (Seibold/Samman 2016). The 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). The main two types of permission set-ups are:

(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.

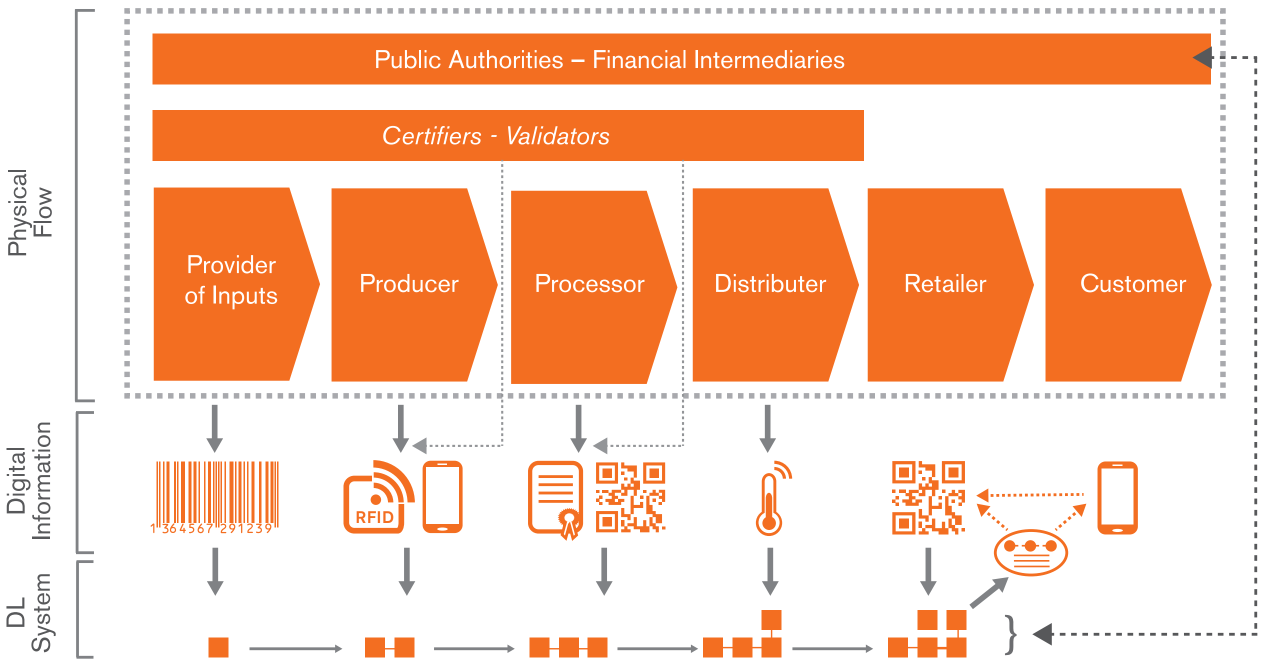
(ii) *Closed – Private – Permissioned*: The access to these types of DL systems is restricted to authorized participants, the rules to read are restricted and the possibilities to write and commit are permissioned. A prominent example is Hyperledger.

The consensus mechanisms often build on incentives for those members that have the interest that a coherent set of distributed ledgers is maintained. 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, which is energy and time intensive. 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). In close DL systems, as for instance a value chain, the consensus mechanisms are less burdensome, as all participants are known and authorized. They are often "extrinsically incentivized" to behave correctly through legal contracts or operational targets (Seibold/Samman 2016: 12). Therefore, consensus mechanisms can be simplified (Tripoli/Schmidhuber 2018).[6]

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 B). 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.

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



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

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 by lead firms to create transparency in specific parts of a sector.

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. Although many DL systems are initiated by lead firms, some projects have also 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 (for an overview of applications in agricultural and food supply chains, see Kamilaris/Fonts/Prenafeta-Boldú 2019). 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. 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 itself. 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 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 (King et al. 2018; 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 themselves (Wüst/Gervais 2018).

Further, the actors in the value chain must be given a digital identity. 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 et al. 2018).

A second challenge refers to the type and scope of the information collected. The type of information that is included in a DL system depends on the purpose 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 rely on GPS data (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 sensible information in the network is not desirable for all companies in a value chain (Wüst/Gervais 2018). Thus, DLT rules must include permissions that provide transparency while respecting sensible and private information, which requires appropriate structures and transparency in the development and operations of such closed DLTs (Accenture 2019: 17).

First examples of the blockchain technologies were realised for wild-caught fish to combat illegal fishing methods and overfishing tuna and other fish (Visser/Hanich 2017). Other DLT applications in the agriculture commodities refer to products that are typically associated with adverse effects in their production, for instance beef and soybeans from South America, which are often linked to deforestation (Accenture 2019). Lead firms in the coffee value chain[7] have recently initiated blockchain solutions to document the production and processing of so-called 'single origin coffees', which are roasted coffees from a single farmer or cooperative. The platform allows coffee consumers to receive information about the different stages of processing 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.

Within the minerals sector, the structural difference between large-scale extractions and artisanal mining is also reflected in the development of DLT applications. Beyond applications on the traceability of diamonds (see Cartier/Ali/Krzemnicki 2018) on Everledger and DeBeer's GemFair project, more recent examples are linked to mineral production in the DR Congo, with a focus on cobalt even though it 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 vehicles and other electronic products, global battery and automobile producers have started initiatives on the traceability of these minerals (Ledger Insights 2019; Shead 2020). The blockchain applications focus on large mines and 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.

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 identify opportunities to 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'. 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.

OPPORTUNITIES AND LIMITS OF DLTS IN GVCS

DL system can lead to higher incomes for upstream actors in sustainable value chains by lower transaction costs due to more efficient transaction processing via smart contracts and due to the willingness to pay higher premiums for documented sustainability. Overall, 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.

DL systems in commodity value chains face however 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. Firstly, the reliability of information depends on the correctness of the data input to the DL. The systems can integrate checks and technical tools such as GPS tracking and digital sensors to link physical goods with the digital layer more directly. However, these technical solutions make the operation of DL systems technically and financially more burdensome and they depend on the technical capacities of the actors and the available infrastructure. These are potentially limiting factor in particular for smallholders in low-income countries. Moreover, 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, as in the example of the coffee value chains. 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 customized for a specific purpose in a given value chain and the permissions to read, write and commit information need to be defined. This includes decisions on what information is collected and stored, who agrees on updates to the DL, and what is published within and outside the value chain. In DL systems established by lead firms, the governance within the DL system often mirrors power asymmetries in the physical value chains and the specific purposes of DL systems defined by the lead firms determine what data are recorded and published. Some of this excluded information, for instance on pricing, might, however, be highly relevant with regard to economic sustainability for smallholders and their empowerment.

Many DL systems are therefore 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 closed nature of DL systems in GVCs can even increase dependencies of upstream actors, in particular if they have fewer permissions in the DL application due to technical or financial limits. In addition, unequal capabilities to analyse value chain data can further strengthen existing power asymmetries. 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.

POLICY IMPLICATIONS

Overall, DL applications have the potential to improve sustainability in value chains of agricultural and mineral commodities, but DL systems are primarily tools to provide reliable information on transactions based on sustainable conditions for smallholders, artisanal miners and workers. The creation of sustainable production and processing is therefore the necessary pre-condition for DL systems to support and enhance sustainability. However, governance and power asymmetries in underlying physical value chains can be constraints for more sustainable practices in a commodity sector. 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. Therefore, greater transparency of transactions and metadata could affect lead firms' power and ultimately the distribution of value-added. As long as closer cooperation among all actors along a value chain is not part of lead firm strategies, legal obligations to trace material inputs and the related productions and processing practices could be used to promote sustainability in GVCs.

Support for DL systems as part of development cooperation must therefore take into account the power asymmetries in GVCs and the implications for the development, purpose and management of DL applications. If technical solutions such as DL systems are to foster more sustainable GVCs of agricultural and mineral commodities, development policies 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.

Beyond the development of the technical infrastructure, this also requires technical and financial capacities by actors in commodity-producing countries in the Global South. In this context, the promotion of cooperatives as more powerful network members in DL systems, but also in the physical value chains, could be an important starting point. Furthermore, alternative marketing routes, e.g. through direct marketing with processors and end-users in the EU in combination with DLTs can be supported in the context of development cooperation. 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. 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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2 Since 2017, the enforcement of a due diligence review or an audit regarding sourcing of conflict minerals has been suspended by the U.S. Securities and Exchange Commission (SEC) (Lynch 2017).

3 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.

4 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.

5 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).

6 In DL applications for supply chains, the consensus protocol can be extended through smart contracts, a software that 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). By integrating performance, monitoring and enforcement of contractual agreements without a central authority or human involvement, DLTs and smart contracts can increase efficiency in supply chains (Tripoli/Schmidhuber 2018).

7 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 (https://www.farmerconnect.com/).