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Research Article

# Blockchain and sustainable supply chain management in developing countries

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ABSTRACT

Theoretical, empirical and anecdotal evidence suggests that there are more violations of sustainability principles in supply chains in developing countries than in developed countries. Recent research has demonstrated that blockchain can play an important role in promoting supply chain sustainability. In this paper we argue that blockchain's characteristics are especially important for enforcing sustainability standards in developing countries. We analyze multiple case studies of blockchain projects implemented in supply chains in developing countries to assess product quality, environmental accounting and social impact measurement. We have developed seven propositions, which describe how blockchain can help address a number of challenges various stakeholders face in promoting sustainable supply chains in developing countries. The challenges that the propositions deal with include those associated with an unfavorable institutional environment, high costs, technological limitations, unequal power distribution among supply chain partners and porosity and opacity of value delivery networks.

## 1. Introduction

The work of commodity producers and farmers in developing countries is undervalued. On January 14, 2019, news website Reuters published a story about an Ethiopian coffee farmer Gafeto Gardo. In 2018, Gafeto received US$0.29 for a kilogram of coffee beans (Maasho & Hunt, 2019). The average price of regular cappuccino in the U.S. in early 2019 was US $4.02 (Byrnes, 2019). For the amount of coffee used to prepare a cappuccino, Gafeto's share translated to less than US$0.01 for every cup of cappuccino sold in the U.S. Similarly, in an article published in NextBillion website, which explores the links between enterprise and development, the executive director of Uganda's National Union of Coffee Agribusinesses and Farm Enterprises (NUCAFE) noted that the country's coffee farmers receive less than 5% of the retail value of coffee beans they grow. He also stated that many Ugandan coffee farmers make less than US$1/day (Nkandu, 2018).

The above examples make it quite clear that less powerful members of supply chains (SCs) such as farmers are underpaid. While ethical consumption campaigns such as Fairtrade exist, their effectiveness has been questionable (Vidal & Provost, 2014). A complaint that has been often levelled is that the current system fails to consistently and accurately document levels and distribution of benefits to various SC actors (Giovannucci & Ponte, 2005).

Some recent research has documented that blockchain can facilitate sustainable SC management (SCM) and hence address unethical behaviors in SCs such as those discussed above as well as environmental challenges (Gurtu & Johny, 2019; Kouhizadeh & Sarkis, 2018; Kshetri, 2021). We argue that by studying blockchain deployment to promote SC sustainability in the developing world, we can gain novel insights that are not possible by analyzing SCs in the developed world. Indeed, prior researchers have noted that developing countries would be early adopters of blockchain in many areas of economic and social life due to their outdated record-keeping systems, a public mistrust of regulators and rapid diffusion of modern ICTs such as smartphones (Kshetri, 2017; Yermack, 2017). One such area could be the development of sustainable SCs.

The importance of this research topic also lies in the fact that most sustainability violations can be found deeper down in SCs in developing countries (Kshetri, 2021). This is because these countries have weak regulations and enforcement mechanisms in areas related to sustainability such as the environment (Fikru, 2014), and child labor practices (Doepke & Zilibotti 2005). Most firms operating in these countries do not go beyond compliance requirements in their sustainability policies (Jeppesen & Hansen, 2004). This is understandable since if developing

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world-based firms invest too much in new technologies, training of employees and purchasing of international certification, their products become too expensive (Jeppesen & Hansen, 2004) making them less competitive.

Due to low levels of trust and high costs of intermediation, addressing sustainability issues in the developing world has been a challenging task (UNCTAD, 2020). Blockchain could be a valuable tool in overcoming these challenges. Prior research has established that this technology plays a key role in creating trust and facilitating disintermediation and decentralization of markets and existing modes of business and governance (Gurtu & Johny, 2019; Kshetri, 2021). Such characteristics are especially important in addressing trust- and intermediation-related issues in developing countries (UNCTAD, 2020). That is, blockchain can be used to replace the need for institutional and personal intermediation. Technological intermediation by blockchain can also provide a major opportunity for fighting corruption in these countries (UNCTAD, 2020), which has been an important contributor to unethical behaviors in SCs (LeBaron, 2020; LeBaron & Crane, 2018).

A number of forces have also contributed to the use of blockchain in facilitating the development of sustainable SCs in developing countries. Especially firms are facing increasing pressures from regulators, activists and consumers to develop sustainable SCs (European Union (EU, 2020). Some entities of governance such as the European Union (EU) have recommended that the use of technologies such as blockchain be explored to enhance SC visibility in developing countries (European Union (EU, 2020). Companies are also under increasing pressure from consumers to be more sustainable. In a survey, 66 % of respondents were willing to pay more for sustainably and ethically sourced products. The proportion was 73 % for millennials (Forbes Africa, 2018). Blockchain can help firms demonstrate the sustainability of their actions to consumers and other stakeholders.

The objective of this study is to address the above issues by offering a theory that articulates the roles of blockchain in monitoring and enforcing sustainability standards in SCs in the developing world. Specifically, the following research question has been addressed: What is the role of blockchain in addressing various challenges related to monitoring and enforcing sustainability standards in SCs in the developing world?

Before proceeding further, we provide some clarifying definitions. Our approach to sustainability is based on triple bottom line (TBL), which considers sustainable actions as those that are economically viable, environmentally sustainable and socially responsible (Jamali, 2006). Economically viable actions are those that contribute to the corporate bottom line and ensure the flow of money in the community via taxes, employment, and other means (Slaper & Hall, 2011). By environmental sustainability, we mean pro-environmental initiatives undertaken by organizations in managing natural resources and the natural environment (Ones & Dilchert, 2012). Actions that contribute to social and distributive justice, improve fairness in the allocation of resources (e.g., by increasing the price paid to commodity producers and farmers in developing countries) or promote the sustainability of community are viewed as socially responsible (Barton, 2000; Dempsey et al., 2011). We define sustainable SCs are those that contribute to one or more of the above outcomes.

The article is organized as follows. We first discuss some background, concepts and facts related to blockchain and enabling technologies in SCM. It is followed by the literature review section, which summarizes previous literatures on challenges in enforcing sustainability standards in developing countries, increasing adoption of blockchain in these countries and blockchain's use in SCs to provide a clear rationale for the current research in the light of what has been done before. Then we discuss how the multiple case study method has been applied. Next, we develop propositions that highlight how blockchain can potentially address various challenges in enforcing sustainability standards in developing countries. In the discussion and implications section, we offer a commentary concerning blockchain's technical potential to address sustainability-related concerns in SCs in developing countries, highlights how economic, technological and infrastructural developments affect the ability to realize such potential and delves into some practical challenges. In the conclusion section, we summarize the main ideas of the paper and discuss the most salient barriers that can prevent blockchain's use to promote sustainability in SCs in these countries.

## 2. Blockchain and enabling technologies in SCM: some background, concepts and facts

In this section, we introduce a primer on blockchain to help readers gain an understanding of this complex topic (Table 1). Blockchain can be viewed as a decentralized ledger that maintains digital records of a transaction simultaneously on multiple computers. After a block of records is entered into the ledger, the information in the block is mathematically connected to other blocks. In this way, a chain of immutable records is formed (Yaga et al., 2018). Due to this mathematical relationship, the information in a block cannot be changed without changing all blocks. Any change would create a discrepancy which is likely to be noticed by others (Kshetri, 2018b).

Blockchains can be permissioned (e.g., Hyperledger Fabric) or permissionless (e.g., Bitcoin and public Ethereum). Permissioned blockchains can be designed to restrict access to approved actors such as SC partners. In a way, permissionless blockchains are like a shared database. Everyone can read everything. However, a user cannot control who can write.

Implementing smart contracts is among blockchain's most transformative applications. Smart contracts execute automatically when certain conditions are met. A smart contract assures a party with certainty that the counterparty will fulfill the promises.

Ethereum, which is the first blockchain platform to make smart

**Table 1**
Explanation of major terms used in the paper.

| Term | Explanation |
|---|---|
| Blockchain | A decentralized ledger that maintains digital records of a transaction simultaneously on multiple computers. |
| Cryptocurrency | A cryptocurrency functions like money, which means that it defines value, serves as a value transfer and can be used for making and receiving payments. Such currencies are on the blockchain and encrypted using cryptography. |
| Ethereum | The Ethereum network is a public blockchain-based open software platform, in which each node can be discovered by and known to other nodes in the network. It has its own cryptocurrency known as Ether. |
| Ethereum Gas | A fraction of an Ethereum token used by a smart contract to pay for the miners' efforts to secure the transaction on the blockchain. |
| Hyperledger Fabric | It is an open-source blockchain platform from The Linux Foundation, which is provided by IBM as "Blockchain as a Service". It is targeted to businesses. Hyperledger facilitates smart contracts by connecting all relevant parties together. Fabric is type of private or permissioned blockchain. Some organizations or government agencies "own" the nodes, who permit the nodes to communicate with each other. Identities and roles of members are known to other members |
| Permissioned blockchain | In a permissioned blockchain, nodes or users are not publicly discoverable. The permission to create smart contracts may also be restricted to approved actors. |
| Permissionless blockchain | A permissionless blockchain can allow anyone to join the network and participate in block verification to create consensus and create smart contracts. Some examples include the Bitcoin and Ethereum blockchains |
| Smart contracts | Smart contracts execute automatically when certain conditions are met. Computerized protocols and user interfaces are used to execute a contract's terms (Szabo, 1994) and to "formalize and secure relationships over public networks" (Szabo, 1997). |

contracts widely available to the blockchain community, is also arguably the most advanced platform for creating and processing such contracts (De Meijer, 2020). While Bitcoin blockchain stores data related to transactions, Ethereum stores diverse types of data such as those related to finance, industry, legal, personal information, community, health, education and governance (State of the DApps. U.D., 2021). These data can be accessed and used by computer programs known as decentralized applications (dApps) that run on Ethereum. Software developers can choose their own 'rules' for ownership, transaction formats and other aspects. Ethereum can thus be customized to offer unique solutions to special needs. It is mainly used to develop B2C applications. In Ethereum, computers connected in an open and distributed network provide the processing power needed to run a smart contract. The computers in the network also verify and record transactions.

The owners of the computers are awarded with Ether tokens for their contributions. Ethereum can be viewed as the first shared global computer. Bitcoin, on the other hand, is considered to be the first accounting ledger shared globally (MIT Technology Review, 2017). Ethereum needs what is referred to as Ethereum Gas in order to execute transactions or smart contracts.

### 2.1. Specific characteristics of blockchain

Three key characteristics of blockchain have been identified – decentralization, immutability and cryptography-based authentication (Kshetri, 2018b).

#### 2.1.1. Decentralization

Blockchain's value proposition is arguably embedded in decentralization. By supporting decentralized models, blockchain can make sustainability-related activities more transparent and produce trust. Blockchain eliminates the need for a trusted third party in the transfer of value and thus enables faster, and less expensive transactions. Even those who are skeptical of the potential of blockchain in many other fields and applications are optimistic in its trust producing capabilities (Hackett, 2017).

#### 2.1.2. Immutability

The term immutable comes from object-oriented programming, in which data structure and operations or functions that can be applied are defined by programmers. Immutable means that once an object has been created and is recorded in a software code, it cannot be modified (Tschantz & Ernst. 2005). Blockchain-based transactions are thus indelible and cannot be forged. The immutability feature makes transactions on blockchain auditable, which can improve transparency. A party can be given controlled access to relevant data. For instance, blockchain's distributed ledger model would allow regulators and authorities to access key data and information related to sustainability (Till et al., 2017).

#### 2.1.3. Cryptography-based authentication

To ensure that only authorized users can access the information, blockchain systems use cryptography-based digital signatures to verify identities of participants. Users sign transactions with a private key, which is generated when an account is created. A private key is typically a very long and random alphanumeric code. Using complicated algorithms, blockchain systems also create public keys from private keys. Public keys make it possible to share information. This feature makes it possible to measure and track sustainability-related outcomes. For instance, if a coffee retailer claims that living wages are paid to coffee farmers, the accuracy and truthfulness of such claims can be assessed by checking the payments to digital wallets assigned to the farmers.

### 2.2. Enabling conditions to facilitate blockchain deployment in SCs in developing countries

#### 2.2.1. Low cost of blockchain deployment and micrometering

Blockchain deployment does not need investment in new devices or hardware. Thus, it is economically justifiable to generate a blockchain code even for small transactions. This is especially important for developing countries.

#### 2.2.2. Low costs and rapid diffusion of the Internet-of-things (IoT) devices

Prior researchers have suggested that blockchain–IoT combination is likely to have a powerful impact on many industries (Christidis & Devetsikiotis, 2016). In this regard, a key observation is that IoT components such as sensors are becoming affordable and accessible. For instance, during 2005–2015, the costs of sensors decreased by a factor of 100 (Lesser, 2015).

#### 2.2.3. High penetration rates of cellphones in developing and least developed countries

Modern ICTs such as smartphones are diffusing rapidly in developing countries, which is likely to make them possible early adoption of blockchain (Yermack, 2017). According to the International Telecommunication Union's (ITU), cellphone penetration rate in developing countries was 99.3 % in 2020. For least developed countries, the proportion was 74 %.

## 3. Literature review

In this section, we focus on three key points. First, as noted, new insights can be gained by extending the existing research on blockchain and sustainability in the context of developing countries. Second, various SC tasks and activities that blockchain facilitates can be used to improve SC sustainability. Third, the existing research on blockchain in developing countries can provide the foundation for studying how blockchain can facilitate sustainable SCs in these countries. In light of these situations, blockchain's impact on sustainability practices in SCs in developing countries would thus represent a promising research opportunity in order to delineate the associated contexts and mechanisms.

This literature review is thus organized around the following three themes: a) Key challenges in enforcing sustainability standards in developing countries; b) Blockchain's roles in meeting key SCM objectives including those that relate to sustainability, and c) Blockchain diffusion in developing countries.

### 3.1. Key challenges in enforcing sustainability standards in the developing world

#### 3.1.1. Institutional challenges

Institutions are the macro-level rules of the game (North, 1990), which include "formal constraints (rules, laws, constitutions), informal constraints (norms of behavior, conventions, and self-imposed codes of conduct), and their enforcement characteristics" (North, 1996, p. 344). Developing countries lack institutional conduciveness to implement sustainability initiatives. For instance, due primarily to lax enforcement and corruption, the seafood trading industry is plagued by problems such as overfishing, fraud, as well as illegal, unreported, and unregulated (IUU) fishing. There are also human rights abuses (Moosa, 2016).

Concerns have also been raised regarding the validity and reliability of auditing methods and third-party certifications (TPCs). Some researchers have suggested that social and environmental audits lack transparency (Ball et al., 2000)

#### 3.1.2. Considerations related to costs and/or benefits

Due to their inability to invest in systems to measure and track relevant data, small firms in developing countries cannot prove their compliance with sustainability standards. For instance, consider grades and standards (G&S), which are arguably among most relevant institutions for the developing world (Reardon et al., 1999). The importance of this stems from the obvious fact that there is a tendency among consumers to demand product quality and safety. Such demands are communicated to the suppliers of products through G&S, which are reflected in certification and labels (Reardon et al., 1999). Note that standards are *"rules of measurement established by regulation or authority"* and the grades are "a system of classifications based on quantifiable attributes" (Jones & Hill, 1994). Meeting G&S often requires huge investments. Many small dairy operations were reported to go out of business in Latin American economies due to their inability to meet G&S standards related to quality and safety for milk products (Jank et al., 2001).

#### *3.1.3. Technical and practical challenges*

Due to market and competition related forces, it is becoming important to ensure that sustainability-related claims are credible and verifiable (Giovannucci & Ponte, 2005). There are, however, significant challenges in achieving such objectives due to existing technologies' limitations in measuring and enforcing sustainability (North, 1999).

To take an example, the global apparel retailer C&A requires its suppliers to respect its ethical standards which include fair and honest dealings with employees, sub-contractors and other stakeholders (Graafland, 2002). There are, however, implementation challenges due to the technical impracticality of assessing various stakeholders' sustainability practices. In terms of indicators related to forced labor, for instance, studies of buyer-led supply chain governance programs have revealed significant gaps between corporate social responsibility (CSR) standards and business practices (LeBaron, 2021). Such gaps can be attributed to opaque and complex SCs that make effective monitoring extremely difficult (Eckert, 2013).

Due to the opacity of modern SCs, unethical practices often go undetected and unpunished. Even if unethical problems such as forced labor are found in a SC, powerful firms often attempt to shift the blame to some "unscrupulous and corrupt intermediaries" and create a false impression that the SC as a whole is run in an ethical manner (LeBaron, 2020; LeBaron & Crane, 2018).

#### *3.1.4. Power distribution and integration related issues in inter-organizational networks*

*3.1.4.1. Unequal power distribution among SC partners.* The world trade arguably mostly benefits multinationals (Herron & Browne, 2015). Researchers have long suspected that the benefits associated with price premiums dilute or even disappear along SCs (Giovannucci & Ponte, 2005). According to a study commissioned by the U.K. government on the production of flowers, coffee and tea in Ethiopia and Uganda, sales of Fairtrade-certified products failed to benefit poor farmworkers. The wages were lower in farms and places that grew Fairtrade flowers or farmers' groups that sold coffee and tea to Fairtrade certified markets compared to farms that were larger, commercial and not Fairtrade-certified (Vidal & Provost, 2014). Some have suggested that Fairtrade's bureaucratic system has negligible effect to change unfair practices (Herron & Browne, 2015).

Thanks to TPC systems, supermarkets' power to regulate the agrifood system has drastically increased. TPCs arguably reconfigured social, political, and economic relations in the global agrifood system (Hatanaka et al., 2005).

*3.1.4.2. Porosity and opacity of value delivery networks (VDN).* SC networks have low degrees of integration and responsiveness. In food supply networks, farmers, processors, distributors, and retailers use different types of documentation systems to track products. Some rely on papers. All these lead to information silos. Challenges such as those related to data silos are more pronounced for developing countries than for developed countries.

Manufacturers thus rely on opaque channels to distribute their products. Products' ownership and custodianship change many times before they reach to end users (Till et al., 2017). For instance, widespread availability of fake drugs in Africa can be attributed to the distribution system's porosity (Yeebo, 2015).

### *3.2. Blockchain's roles in meeting key SCM objectives*

Blockchain can help achieve various SCM goals including those that relate to sustainability (Di Vaio, & Varriale, 2020; Gurtu & Johny, 2019; Kshetri, 2018a). Using blockchain, it is possible to make indicators related to sustainability transparent, quantifiable and more meaningful (Gurtu & Johny, 2019; Kshetri, 2018a). Especially in combination with other technological advancements, blockchain can help firms achieve TBL goals (Treiblmaier, 2019). For instance, Venkatesh et al. (2020) have demonstrated that by combining blockchain with the IoT and big data, firms can monitor and evaluate SCs' social sustainability performance.

Blockchain's key features such as decentralization and immutability make it an ideal tool to improve SC traceability by addressing various shortcomings of traditional SCs (Kim & Laskowski, 2018; Toyoda et al., 2017). Immutable data related to product dimensions and other key characteristics, such as nature, quality, quantity, location and ownership can play key roles in addressing such issues (Saberi et al., 2018). Despite traditional SC information systems' capability to uniquely identify products, they perform poorly in traceability mainly due to data silos. That is, some SC data are accessible by some participants but are isolated from other participants. In order to be able to trace ingredients across multiple tiers of a SC, data must be shared in a tamper-proof way and must be accessible to relevant parties (Westerkamp et al., 2020).

Improving the governance structures in SCs is a key mechanism by which blockchain can promote sustainability. This technology can provide visibility and document provenance and allow the access of permissioned data to facilitate the automation of tasks such as payments, and settlements (Narayanaswami et al., 2019). For instance, blockchain can be used to create a SC map showing a transaction and information flows. Such flows can help understand the weakest links and the degree and nature of risks and threats involved (Min, 2019) and reduce opportunistic behaviors (Schmidt & Wagner, 2019). For instance, blockchain's transparency help ensure that middlemen and other actors do not engage in unethical behaviors (Treiblmaier, 2019).

Disintermediation is a further mechanism by which blockchain can transform SCs (Gurtu & Johny, 2019; Queiroz et al., 2019). Some of the intermediary tasks are likely to be replaced by blockchain (Tönnissen & Teuteberg, 2020). Transactions thus can be conducted without relying on a third party's trust. Instead, participants rely on distributed trust that is based on the consensus of the network of other users (Francisco & Swanson, 2018). These mechanisms are likely to reduce transaction costs and facilitate market-oriented practices (Cole et al., 2019; Schmidt & Wagner, 2019).

Blockchain can also help provide product information to consumers to increase their confidence about the quality of products (Nikolakis & Krishnan, 2018). Blockchain-based product traceability is thus key in bringing SC transparency (Banerjee, 2018; Hald & Kinra, 2019), which can enhance consumers' perception of a firm's sustainability practices.

Regarding the mechanisms through which blockchain-led transparency could reduce unethical behaviors, prior research has noted that under some conditions, behaviors that are viewed as unfair may be punished (Fehr et al., 1997). For instance, in ultimatum game experiments, researchers found that individuals are willing to forego some monetary benefits in order to punish unfair practices (Camerer & Thaler 1995; Roth, 1995). This means that when there is the possibility of being punished, firms are less likely to engage in unfair behaviors. A challenge in the non-blockchain world, however, is that there is no data to assess the fairness of some participants' behaviors. Blockchain-based transparency makes it more difficult to hide unfair or unjust practices.

### 3.3. Blockchain in the developing world

Prior researchers have also looked at the adoption and impacts of blockchain in the developing world (Kshetri & Voas, 2018). Yermack (2017) suggested three factors' crucial roles in explaining developing countries' possible early adoption of blockchain: a) inadequate and outdated record-keeping systems in these countries may increase the appropriateness of blockchain in filling this void; b) a public mistrust of regulators could make blockchain's role as a trust producing machine more compelling; c) modern ICTs such as smartphones are diffusing rapidly, which would make it relatively easy to adopt blockchain. Regarding the impacts, prior researchers have argued that blockchain can play a major role in addressing various challenges such as fighting corruption (Kenny, 2017; Kshetri & Voas, 2018), improving the protection of property rights (Kshetri, 2017) and creating secure digital identities (Kshetri, 2020).

Blockchain can also be used as an important tool for humanitarian and development applications such as handling of vaccines by aid groups (Till et al., 2017) and helping refugees (Kshetri, 2017, 2020). One example of the latter is the World Food Program's (WFP) "Building Blocks" pilot started in 2017. In the first stage, Building Blocks distributed food and cash assistance to needy families in Pakistan's Sindh province. In May 2017, the WFP started distributing food vouchers in Jordan's refugee camps by delivering cryptographically unique coupons to participating supermarkets (Kshetri, 2020).

## 4. Methods

We build theory from multiple cases (Eisenhardt & Graebner, 2007; Kshetri, 2016a). We selected only cases for which sufficient information could be obtained from secondary resources. Note that archival data is among a variety of recognized data sources for case studies (Eisenhardt & Graebner, 2007).

Following Eisenhardt (1989), we selected eight cases. In order to select the cases, we combined two approaches: extreme method, and diverse method (Seawright & Gerring, 2008). More specifically, our process started with extreme case method. It evolved over time in order to implement different requirements and recommendations.

In the extreme case method, cases with extreme values on the independent (X = firm characteristics) or dependent variable (Y = use of blockchain in demonstrating sustainability) of interest are selected (Seawright & Gerring, 2008). The cases we selected are extreme in the sense that they are among the earliest blockchain adopters in enforcing sustainability standards in SCs. In particular, prior researchers have suggested that best practices models are good candidates for case research (Eisenhardt, 1989).

If researchers have some idea about other factors that might affect Y (the outcome of interest), other case selection methods can be pursued (Seawright & Gerring, 2008). We utilize a diverse case method to select firms deploying blockchain in enforcing sustainability standards in SCs. A key goal is to achieve a maximum possible variance along relevant dimensions (Seawright & Gerring, 2008). The idea in this method is to select cases to represent full ranges of values characterizing X, Y, or some relationships between them (Seawright & Gerring, 2008).

As discussed above, prior research indicates that blockchain's transparent, immutable, and verifiable records can help buyers to evaluate and sellers to demonstrate product quality (Saberi et al., 2018), protect the natural environment by promoting green SCs (Kouhizadeh & Sarkis, 2018) and monitor and evaluate social sustainability performance of SCs (Venkatesh et al., 2020). These themes also emerged from our cases of companies deploying blockchain in enforcing sustainability. Specifically, we considered the measurement of the following two dimensions: (a) product quality and environmental impacts, and (b) societal impacts. In order to achieve diversity, we selected cases with different combinations of these two focus areas as follows.(case number in square brackets []): [1] Bext360, [2] Provenance, [3] BanQu, [4] Alibaba, [5] Walmart, [6] Breau Veritas, [7] Swiss Coffee Alliance (SCA), [8] Coca-Cola. Cases [1], [2] and [3] focus on both (a) and (b). For cases [4], [5] and [6], ensuring product quality has been the main area of importance. The main aim of blockchain systems in cases [7] and [8], on the other hand, is to promote a positive societal impact.

We briefly illustrate the above with two examples: BanQu and SCA. The non-cryptocurrency blockchain platform BanQu places emphasis on both on (a) and (b). In 2018, it teamed up with Anheuser-Busch to promote SC transparency in its subsidiaries in Zambia (Zambian Breweries) and Uganda (Nile Breweries). Regarding (a), when farmers supply their crops to Anheuser-Busch's subsidiary Nile Breweries, the company's officials check for quality and other details before entering data in the BanQu system (Equator News, 2019). Anheuser-Busch InBev has also viewed that BanQu supports its agriculture sustainability goal (ABInBev, 2019). This means that BanQu's system places emphasis on product quality and environmental impacts.

As to (b), BanQu's mission is also to establish economic identities and proofs of record ("economic passport") for unbanked persons living in extreme poverty. It defines economic identity as "the marriage of identity and commerce, resulting in a global, vetted, and manageable asset" (Ramirez, 2017). A farmer receives an SMS, which shows the quality, quantity and price of the crops sold. Such records are with the farmers and the buyer (e.g., Nile breweries). The farmer can access the payment by presenting the code received in the SMS to the partner bank or a mobile telecom company.

BanQu thinks that blockchain-based verifiable digital identity can help disadvantaged groups establish ownership, business assets, and production values. Such an identity would thus help them to engage in economic transactions and participate in the global economy. Thus, social impacts have also been a focus area for BanQu's system.

On the other hand, SCA uses Ambrosus' sensor-to-blockchain technology to fight unethical distribution of profits in the global coffee SCs. The participants include SCA's network of farmers, roasters, product developers, manufacturers and retailers. Thus, the organization is more focused on social impact measurement rather than product quality and environmental impact measurement.

### 4.1. Ensuring accuracy and quality of data

We made efforts to ensure the accuracy and quality of information. We assessed data's internal consistency. As suggested by prior researchers (e.g., Kshetri, 2018a), we evaluated different data items for the same point in time. Additionally, the same data items have been analyzed for different points in time. For instance, for Walmart various steps and processes associated with deploying blockchain to verify and enforce sustainability were compared for October 2016 (food safety and traceability protocols tests started in China and the U.S.), February 2017 (completion of the pilots) and May 2017 (release of the results of the tests), commercial launch of its blockchain traceability platform (June 2019) and expanding the platform to more product categories (November 2020).

The reputation and trustworthiness of the source as well as content of data are important. We mainly relied on information from reputable third parties instead of taking directly from the websites of organizations chosen in the analysis. We also corroborated data and information from multiple sources.

Timeliness and currency of the data are of equal importance. We followed the latest news items related to the cases chosen. In addition, we also visited the websites of the relevant companies for up-to-date data and information.

### 4.2. Patternmatching theory and data

Prior researchers have suggested that theory and data need to be "patternmatched" and propositions need to be consistent with the selected cases (Eisenhardt & Graebner, 2007). To this end, Table 2 and Fig. 1 provide a visual theory summary. They explain how the framework developed can be applied to understand the roles of blockchain in monitoring and enforcing sustainability standards in the developing world.

## 5. Blockchain's roles in enforcing sustainability standards in developing countries: seven research propositions

In this section, we develop seven propositions regarding blockchain's potential in overcoming sustainability-related compliance problems in developing countries.

### 5.1. *The propositions*

Eisenhardt & Graebner (2007) suggested to provide a visual theory summary in the form of "boxes and arrows" diagram or summary table in case study research. To this end, Fig. 1 presents a preliminary conceptual framework described by the propositions we developed. This Figure depicts the framework graphically and presents characteristics of blockchain and enabling technologies in relations to the enforcement of social and environmental sustainability standards in SCs in developing countries. Table 2 presents blockchain's potential in addressing various sustainability-related challenges.

#### 5.1.1. *Institutional*

*5.1.1.1. Sustainability-related regulatory enforcement.* Blockchain can strengthen the enforcement of regulations and standards. Enforcements can be implemented at three levels: first-party (self-enforcement), second-party (one party retaliating against the other), and third-party (e.g., formal coercive enforcement measures by the state) (North, 1999). First it is important to emphasize that third-party enforcement mechanisms, which are often formal coercive measures by the state, have been ineffective in the developing world (Kshetri, 2016b). This increases the relative importance of the first two types of enforcement.

Prior research has suggested that modern technologies such as the IoT have greatly facilitated the first-party enforcement and the second-party enforcement (Kshetri, 2016b). Blockchain can strengthen the governments' enforcement powers and sanctions against individuals or organizations that breach regulations. For instance, as mentioned, blockchain allows regulators and authorities to access key data and information (Till et al., 2017). Indeed, regulators have been involved in the blockchain systems of Walmart [case 5] and Coca-Cola [case 8].

Specifically, Walmart used Hyperledger platform to build the system (Hackett, 2016). This means that the copies of the records are stored and validated by other participants known as peers. Walmart is responsible for setting up its peers to participate in the network. The peers in such SCs also include relevant government agencies (IBM, 2017).

According to the Walk Free Foundation, in 2016, 40.3 million people were living in modern slavery, who were forced to work under threat against their will or were living in a forced marriage (Walk Free Foundation, 2018). In 2018, US$354 billion worth of products that were at-risk of being produced by forced labor were imported by G20 countries (Walk Free Foundation, 2018). Prior researchers have suggested that due to the opacity of modern SCs, despite the existence of problems such as forced labor, powerful firms create a false impression to mislead the public about their unethical practices (LeBaron, 2020; LeBaron & Crane, 2018). Coca-Cola and the U.S. State Department have teamed up to fight the use of forced labor by using blockchain's to create a secure registry for workers and their contracts. The idea is that blockchain's validated chain of evidence is likely to encourage SC participants to comply with the terms of the contracts. The Bitfury Group will build the blockchain platform and Emercoin will provide blockchain services. The

**Table 2**
Blockchain to enforce sustainability-related standards: Patternmatching theory and data.

| | Key challenges and blockchain's potential to address them | Examples [Case No.] |
|---|---|---|
| Regulative institutions ($P_1$) | Lack of institutional conduciveness to implement sustainability, lax enforcement and corruption: Blockchain makes complete and verifiable records available and allows regulators' access to data | Regulators' involvement in Walmart's solution [3]. The U.S. Department of State's collaboration with Coca-Cola [8]. Provenance: Records of the SCs of the fishing industry, which is likely to stop IUU fishing and human rights abuses [2] |
| Normative institutions ($P_2$) | External auditors' attestations to environmental and social reports are of poor quality (Ball et *al*, 2000): blockchain's transparency and authenticity would allow concerned parties to verify SC sustainability data themselves | Bext360's [1] Stellar's application ensures secure and transparent payments directly to farmers when their products are evaluated and sold. SCA's use of Ambrosus' sensor-to-blockchain to fight unethical distribution of profits in the global coffee SCs [7]. |
| Cognitive institutions ($P_3$) | Market forces have increased the importance of ensuring that sustainability-related claims are credible/ verifiable (Giovannucci and Ponte, 2005): Blockchain makes it possible to provide consumers with detailed information in a trustworthy manner | Provenance makes it possible for end customers to verify a product's origins through a mobile app [2]. Walmart's system: possible to track and view details about products, farms, factories, batch number, storage temperature and shipping instantly [5]. Breau Veritas continual verification rather than samples: highly reliable information [6]. |
| Cost-benefit considerations ($P_4$) | Systems such as G&S require huge investments and high transaction costs to measure relevant dimensions in exchange/ enforcement, making it unaffordable for small players (Jank et al., 2001; North, 1999): Blockchain's low *marginal cost economics and* decline in costs of sensors/other technologies | Provenance require minimal investment: cellphones and RFID tags [2]. Walmart can trace and pinpoint the source of integrity violation in a crisis: strategic removals of affected products [5]. BanQu uses Ethereum, the average cost of transaction in 2018: US$0.03 [3]. |
| Technical and practical ($P_5$) | Difficulties associated with measurement and documentation of sustainability-related issues and effectively accessing and communicating benefits (Giovannucci and Ponte, 2005): Blockchain can confirm everything related to the SC history–the maturity of IoT applications further increases blockchain's value proposition | Bext360 smart contracts to bring transparency to the SCs [1]. Walmart: if an item is found to be spoiled or the source of a product is compromised, the system would act proactively in order to ensure food safety [5]. |
| Unequal power distribution among SC partners ($P_6$) | Growing power of supermarkets–benefits of price premiums dilute/ disappear along the value chain (Giovannucci and Ponte, 2005; Hatanaka et al., 2005): Blockchain's data transparency and smart contracts to govern key | Bext360: participants make data transparent: records of all relevant details [1]. SCA: sensor-to-blockchain technology aims to fight exploitation of farmers by powerful SC partners with the help of immutable records of transactions [7]. |

(*continued on next page*)

**Table 2** (*continued*)

| | Key challenges and blockchain's potential to address them | Examples [Case No.] |
|---|---|---|
| | processes can ensure that farmers are paid fairly. | |
| Porosity and opacity of VDN ($P_7$) | SCs are weak and opaque (Till et al., 2017): Blockchain can create a permanent real-time record of a SC | Alibaba: detailed and complete records of the SC history of food products [4]. |

State Department has committed to provide its expertise on labor protection (Chavez-Dreyfuss, 2018).

Among the key benefits of blockchain in SCM include enhancing product safety, fighting counterfeit products (Cole et al., 2019), facilitating traceability (Hald & Kinra, 2019) and bringing SC transparency (Banerjee, 2018). These are especially important in China which suffered a number of food scandals. The Chinese government has been blamed for its lack of ability to ensure food safety. Food security has thus been a critical national interest in China (Olavsrud, 2016). Walmart China's [case 5] future plan is to synchronize data of its Traceability Platform with similar platforms of local governments as well as those of its suppliers. The goal is to provide customers with high quality and safe food products (Duckett, 2019).

As noted above, the seafood trading industry suffers from IUU fishing and human rights abuses (Moosa, 2016). Due to the complex and opaque nature of SCs (LeBaron, 2020; LeBaron & Crane, 2018), measurement and enforcement of sustainability practices are problematic. For instance, seafood trades source from hundreds of boats, which makes the full quality control a challenging task. Some sustainable tracking systems are largely based on papers and reports. There is also the lack of supervision. In this regard, Provenance's system [case 2] aims to address such challenges. In 2016, it conducted a pilot project to track fishes caught in Indonesia using cellphones and RFID tags. When a product changes hands, it is automatically added to the blockchain system. The end customers can verify the product's origins through a mobile app. The system thus provides complete and verifiable records of the fishing industry's SCs. The above discussion suggests the following.

**P1**. Blockchain can strengthen sustainability-related regulatory enforcement in SCs.

*5.1.1.2. The roles of trade associations, industry bodies and TPC agencies.* In the current global capitalism, non-state actors such as NGOs, trade and industry associations and TPC agencies play a central role. These actors provide normative framework that is being increasingly used by corporations to achieve social legitimacy (Giovannucci & Ponte, 2005). However, as noted above, concerns have been voiced that auditors and TPCs lack transparency, validity and reliability (Ball et al., 2000).

Prior researchers have noted the roles of blockchain-led disintermediation in disrupting key industries (Queiroz et al., 2019; Tönnissen & Teuteberg, 2020). Blockchain could make the roles of actors such as TPC agencies irrelevant. For instance, in SCA's blockchain system [case 7], data generated by sensors related to the activities of farmers, roasters, product developers, manufacturers and retailers are put into blockchain. Likewise, Bext360's system [case 1] aims to ensure secure/transparent payments directly to farmers when coffee and other products are evaluated and sold. Digital wallets are assigned to each farmer, each machine as well as a machine owner. First-hand data related to product evaluation and payment to coffee growers are on a blockchain system. Access to such data allows interested parties to verify sustainability performance. Thanks to blockchain-led traceability and transparency (e.g., Banerjee, 2018; Hald & Kinra, 2019) of value chains, concerned parties do not need to rely on TPCs. The above discussion leads to the following proposition

**P2**. Blockchain can increase transparency in sustainability-related activities, which will decrease the roles of trade associations, industry bodies and TPC agencies in SCs.

*5.1.1.3. Consumer confidence about manufacturers' claim regarding sustainability.* Consumers are increasingly concerned about the sources of their food, beverages and other products (Scott, 2017). Prior research has suggested that there is an increasing level of consumer awareness and desire for products meeting sustainability standards (Giovannucci & Ponte, 2005).

However, demand of sustainably sourced products has not been high enough. In 2014, the U.K. retailer Tesco stocked only three Fairtrade wines (Kshetri, 2021). It suggested that the demand was not significant. This situation is somewhat paradoxical. An explanation for such an

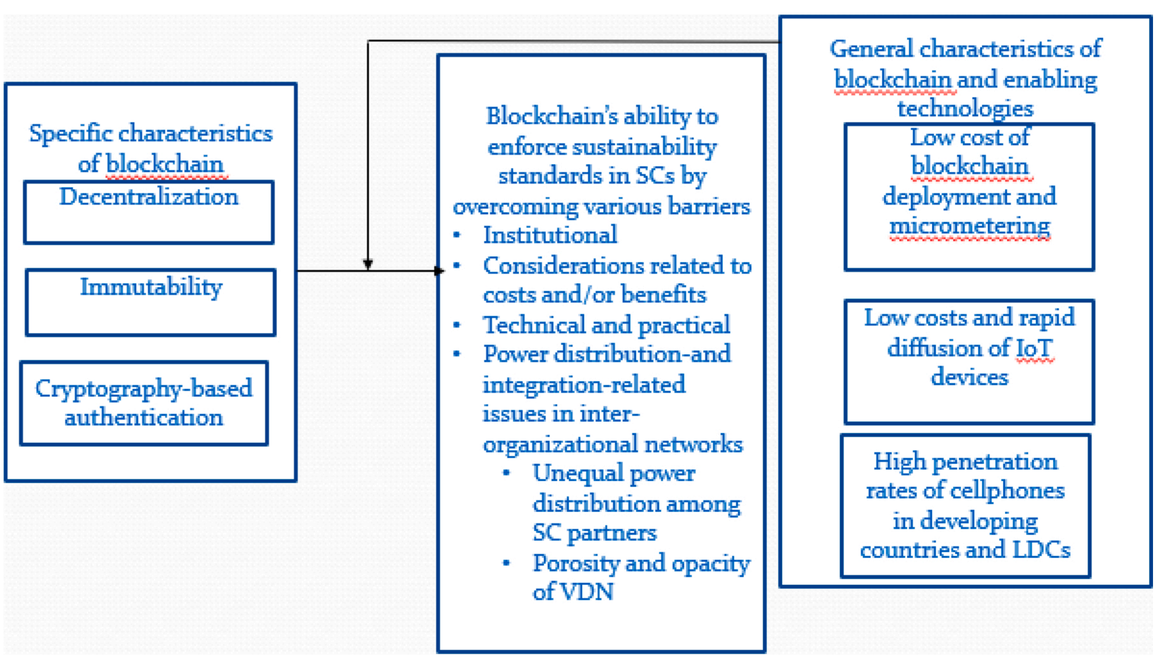


**Fig. 1.** Characteristics of blockchain and enabling technologies in relation to the enforcement of sustainability standards in SCs in developing countries.

anomalous behavior might be the lack of mechanisms to ensure sustainability-related performance of products.

There is thus a weak relationship between what consumers say, and what they actually do in regard to the consumption of sustainable products (Giovannucci & Ponte, 2005). These can be attributed to consumers' lack of trust in value chain actors such as manufacturers of sustainable products and certifiers. There are problems related to the lack of effective communications between manufacturers and consumers. For instance, messages to consumers regarding the achievements of sustainability programs are unclear. Some of the major obstacles are related to measurement and documentation. Such problems are especially apparent in some eco-friendly aspects such as biodiversity benefits and improvement in soil tilth (Giovannucci & Ponte, 2005).

As mentioned, documenting information related to soil's physical condition in relation to its suitability for planting and growing crops–soil tilth–is challenging and even impossible. Various factors determine tilth, which include the formation and stability soil particles, moisture content, degree of aeration, water infiltration rate and drainage. The IoT makes measurement of these parameters feasible, cost-effective and practical. Blockchain, on the other hand, makes it possible to communicate to consumers in a trustworthy and transparent manner.

Second, many consumers have a low degree of trust in the sustainability labelling systems, which can be easily manipulated. False labelling makes it difficult, even impossible, for consumers to distinguish between genuine and fake products (Grote et al., 1999). Blockchain's transparency and immutability can be used to provide a tamper-proof system and communicate information related to a number of product dimensions to demonstrate sustainability (Kouhizadeh & Sarkis, 2018; Saberi et al., 2018). For instance, Provenance's platform [case 2] allows end customers to verify a product's origins through a mobile app. Likewise, Bext360's applications [case 1] make it possible to track coffee beans from the farmer to a coffee shop.

Similarly, in 2018, Alibaba [case 4], started using blockchain to track international shipments to China sold on its online marketplaces supplied by Australia's healthcare supply firm Blackmores and food company Anchor and New Zealand's dairy product maker Fonterra. In Australia, it worked with s the government postal services provider AusPost and multinational professional services network of firms PwC to develop blockchain solutions. Each imported item is assigned a unique QR code. By scanning the code, consumers can see details about the product. Alibaba has also taken measures to strengthen the security of QR codes in order to make counterfeiting impossible or extremely expensive. Alibaba launched its "Blue Stars" campaign in 2015 for high-end food products. The campaign used the next generation "dotless" QR-codes. Participating merchants selling on Alibaba's online marketplace Taobao can attach a label containing a QR-code with colorful image with each package to verify the authenticity (Russell, 2014). A secure scanner is used to scan the QR-codes. Each QR-code is unique and cannot be duplicated (Williams, 2015). Theoretically it is possible for counterfeiters to sell fake goods with legitimate Blue Stars QR-codes. To do so they can buy legitimate products, get enough genuine QR codes and put them on the packages. However, each item has a unique QR-code identifier. When a customer receives the product ordered online and scans the code, it will "burn". This means that each code can be used only one time (Alba, 2015). This makes fraudsters' business models less attractive. In this way, blockchain platform would track shipments in real-time and improve security and transparency in food SCs.

Likewise, Walmart's [case 5] blockchain system makes it possible to track and view details about products, farms, factories, batch number, storage temperature and shipping instantly. These details help assess the authenticity of products, and expiry dates (Yiannas, 2017). It can thus ensure that the food consumers are eating is right and authentic.

Finally, blockchain can provide access to rich and detailed information about products, which is likely to increase consumers' confidence. For instance, Breau Veritas [case 6], which provides testing, inspection and certification services, has developed blockchain-based consumer facing food traceability system (http://www.origin.bureauveritas.com//). Relevant participants share records and validate transactions. It provides information from continual verification rather than only samples. By flashing a QR code, shoppers can see a product's history and make informed purchase decisions. In this way, blockchain can resolve ethical dilemmas consumers face in their decision to buy sustainable products. It is proposed:

**P3.** Detailed and verifiable information provided by blockchain-based systems can increase consumer confidence about manufacturers' claim regarding sustainability-related standards in SCs.

#### *5.1.2. Considerations related to costs and/or benefits*

A key challenge that developing world-based firms face in demonstrating sustainability of products is related to high costs of relevant technologies (Jank et al., 2001). Blockchain deployment is attractive from a cost-benefit point of view. As mentioned, the most notable trend is the sharp decline in the costs of sensors and other associated technologies.

SCs also exhibit a high degree of digitization thanks to technologies such as cloud computing, big data, artificial intelligence (AI), and the IoT. Consequently, physical objects can communicate with each other. Blockchain arguably is the missing element in this hyper-digitization (IFC, 2017). An encouraging aspect, however, is that most blockchain transactions are relatively inexpensive once other enabling systems have been established. For instance, BanQu [case 3] uses Ethereum. In 2018, the average cost of transaction in Ethereum network was US$0.03 (Yalovoy, 2018). One of the key applications of blockchain in developing countries is creating secure digital identities (Kshetri, 2020). To register a farmer's identity, companies such as BanQu need to execute a few blockchain transactions at a low cost (Kshetri, 2020)

The favorable economics of cheap sensors can be realized due to the availability of reliable wireless communications worldwide, better algorithms, cloud computing, and big data. Blockchain system developed by Provenance [case 2] requires minimal investment since it utilizes cellphones and RFID tags to track fishes.

SC activities involving even small quantity of products can be recorded on blockchain. Utilizing data related to diverse indicators such as motion, temperature, humidity, and chemical composition from IoT devices, blockchain can cost-effectively confirm SC history of food products (O'Marah, 2017).

Blockchain systems can also be used to create a SC map with transaction and information flows, which would help to analyze the weakest links as well as risks and threats involved (Min, 2019). For instance, in situations involving a food contamination and foodborne illness, specific batches of products can be pinpointed by scanning a barcode on the packaging. Retailers do not have to recall the entire product line. It is also easy to locate other products from the same batch. Blockchain can thus significantly reduce costs and increase the speed with which actions are carried out. Returning to the Walmart [case 5] example, in 2017, the company released the results of the food safety and traceability protocols. Walmart reported that blockchain helped to drastically reduce the time taken to track foods (Higgins, 2017). Specifically, the tests performed on. mangoes revealed that tracing food origins could be handled in 2.2 s. Within this time frame, Walmart located a mango's' identifying details (Hackett, 2017). Due to reduced workload to trace products, blockchain can reduce labor costs and food wastes in case of a recall (O'Marah, 2017). Such a mechanism can contribute to the corporate bottom line and economically viability of actions, which lead to sustainability (Slaper & Hall, 2011).

In the early phase, companies such as Alibaba [case 4] limited blockchain-based tracking to expensive products. Blockchain deployments have been gradually expanded to more products. Walmart China commercially launched its Blockchain Traceability Platform in June 2019. By that time, 23 product lines sold in China used the platform (Duckett, 2019), which increased to more than 100 by November 2020 (Marquez, 2020). This means that blockchain deployment from SCs is becoming more attractive from a cost-benefit perspective. The preceding discussion can be summarized as:

**P4**. Blockchain's micrometering, low marginal costs of investment and the ability to pinpoint the source of violations of sustainability standards would lead to attractive operational benefits in enforcing such standards in SCs.

#### *5.1.3. Technical and practical challenges*

It is often impractical to assess various stakeholders' sustainability practices due to technical limitations (North, 1999). Blockchain-based applications in SCs are the result of advancements in multiple technologies and concepts such as P2P networking, cryptographic hash functions, and digital signatures. Blockchain, in combination with other technologies, can make measurements of sustainability-related indicators possible.

To take an example, Bext360 [case 1] uses Stellar blockchain and smart contracts to measure important sustainability-related indicators to bring transparency in the SCs of coffee and other commodities. Farmers' coffee cherries and coffee parchment deposited at a collection station are analyzed with its bextmachines, which employ smart image recognition technology machine vision, and machine learning. The bextmachines sort them to assess the quality. The system categorizes coffee beans and assigns a price (Knapp, 2018). Farmers that supply bigger and riper cherries are paid more. Each coffee bean is also assigned a unique ID, which makes it possible to trace and track.

Using a mobile app, relevant parties can negotiate a fair price (Scott, 2017). The app also determines the identity of the person selling the products. Farmers get paid via a mobile app. Using Bext360's API, intermediaries such as wholesalers and retailers embed the technology into their websites, marketing, PoS and SCM systems. This level of transparency could not be possible without blockchain.

The bextmachines link the output to crypto tokens. Details of the transactions such as farmer identification, quality, purchasers and payouts are recorded (bext, 2018).

In 2018, Bext360 teamed up with farmers' co-ops, the U.S.-based coffee roaster Coda Coffee, and Uganda-based coffee exporter Great Lakes Coffee to release the world's first blockchain-traced coffee. Each coffee packet is given a QR code. Customers can scan the code to see relevant details such as collection at the coffee farm, washing, drying, roasting, exporting and selling at retail stores (Cadwalader, 2018).

Bext360 also worked with the Netherlands-based Moyee Coffee and the social enterprise FairChain Foundation to produce blockchain-traced coffee. The new brand of coffee product line is called Token. By June 2018, 60,000 kg of blockchain-traced coffee was exported from Ethiopia to Amsterdam (bext, 2018).

Bex360 is expanding into other sectors. It announced a partnership with Amsterdam-based startup accelerator Fashion for Good, which focuses on social and environmental impact in the fashion industry. The goal is to track the entire value chain of cotton. Clothing companies are facing pressures to ensure fair trading practices. Market pressure has also forced these companies to use organic cottons (Knapp, 2018).

Prior researchers have examined how blockchain can reduce opportunistic behaviors (Schmidt & Wagner, 2019). Bext360's case [1] makes it clear that the possibility of manipulation by middlemen or large buyers can be reduced if quality related decisions are made by machines rather than by human minds.

In Walmart's [case 5] system, if an item is found to be spoiled or the source of a product is compromised, the system would act proactively to ensure food safety. As noted above, various pieces of information are tracked. RFID tags, sensors and barcodes, which are already widely used across many SCs, provide relevant data (Kharif, 2016). Based on above discussion, the following proposition is presented:

**P5**. Blockchain deployment in SCs can increase the technical possibility of measuring sustainability-related indicators and effectively communicating them to relevant participants.

#### *5.1.4. Power distribution-and integration-related issues in inter-organizational networks*

*5.1.4.1. Unequal power distribution among SC partners.* Current institutional arrangements in SCs favor big multinationals such as global retailers (Giovannucci & Ponte, 2005; Herron & Browne, 2015) and allow these actors to engage in unethical practices with impunity (LeBaron, 2020, 2021; LeBaron & Crane, 2018). Blockchain has the potential to challenge this unequal power distribution and fight unjust acts. As noted earlier, ultimatum game experiments have revealed that individuals are willing to sacrifice some monetary benefits to punish unfair practices (Fehr et al., 1997; Camerer & Thaler 1995; Roth, 1995). Blockchain-led transparency (Banerjee, 2018; Hald & Kinra, 2019) is likely to make big multinationals' and global retailers' unfair treatment known to consumers and other stakeholders. When there is the fear of punishment, these powerful actors are less likely to engage in unfair or unjust practices.

In Bext360's system [case 1], relevant parties such as companies, farmers, and co-ops make data transparent. The system creates records of all details such as where coffee beans came from, and who paid how much. Likewise, the SCA's [case 7] sensor-to-blockchain technology aims to fight exploitation of farmers by powerful SC members such as retailers with the help of immutable records of transactions.

The above examples demonstrate that blockchain could address various sustainability-related challenges in inter-organizational relationships. A common thread runs through these systems is that blockchain can promote transparency and hence, accountability among SC participants. Overall, with blockchain-led transparency, economic injustices such as slavery and exploitation of workers in the global commodity markets as discussed in the opening of this article can be identified and alleviated. The above leads to the following:

**P6**. Blockchain can promote transparency and accountability in sustainability-related activities in SCs, which will increase the empowerment of less powerful participants.

*5.1.4.2. Porosity and opacity of VDNs.* In light of the concerns regarding SC silos and weak security practices (Zailani et al., 2015), blockchain-led traceability and transparency (Banerjee, 2018; Hald & Kinra, 2019) can play a key role in achieving a higher degree of integration. In case of product recalls, blockchain can be used to register relevant information when an item changes ownership. The technology can track raw materials as they move through SCs. Blockchain can also be used to register updates, patches, and part replacements applied to any device.

Blockchain has the potential to address the porous nature of distribution networks. The systems such as those of Alibaba [case 4] and Walmart [case 5] provide detailed records of the SC history of food products. They are likely to protect consumers against products that are counterfeit or those that use low-quality ingredients. By reducing counterfeit risks and recalls, blockchain can help companies improve the economic viability of their actions and hence the bottom line, which is a key component of sustainability (Slaper & Hall, 2011).

Blockchain-based application can be deployed even in places with limited infrastructural supports. Aid groups can track medical supplies as they move from the factory to the patient. For instance, smartphones can be used to tag vaccines with a permanent real-time record to track steps such as unloading the shipments at the airport and delivering to a village clinic by a courier service. The records provide the locations and persons dealing with the medicine, which are available to all relevant parties (Till et al., 2017). Thus, we propose:

**P7**. Blockchain can reduce the extent to which fake, counterfeit and low-quality ingredient products enter the SCs.

## 6. Discussion and implications

Blockchain clearly has the technical potential to address sustainability-related concerns in SCs in developing countries. This technology can help tackle inefficient regulatory and supervision standards. For instance, some countries are characterized by lax enforcement and corruption in the yellow fin tuna industry (Moosa, 2016). Auditors can identify frauds only after they have occurred. The current system lacks mechanisms to track and control problems as they are developing (Till et al., 2017). In the blockchain world, monitoring and enforcement occur in real time. In this way, blockchain can be an effective law enforcement tool. Especially in permissioned blockchain such as Hyperledger, relevant government agencies can act as nodes or peers, which would allow them to monitor SC activities closely.

Prior researchers have suggested that blockchain may replace some of the intermediary tasks (Tönnissen & Teuteberg, 2020). In particular, blockchain could make the roles of actors such as TPCs less relevant. In the coffee industry, for instance, costs related to paperwork and physical inspection are estimated to be as high as US$0.91 per pound (https://moyeecoffee.ie/blogs/moyee/world-s-first-blockchain-coffee-project). As noted above, systems such as those launched by Bext360 can automate the functions performed by TPCs.

Consumers can be empowered by blockchain systems because they can verify sustainability-related information themselves (Saberi et al., 2018). Companies such as Alibaba and Bext360 are already providing such information via QR codes. Currently there is the lack of trust in certifiers and inquisitors. For instance, there have been many cases of organic certification fraud. In this regard, blockchain makes certification fraud more difficult. Moreover, the degree of details and verifiability of records would increase the quality of information. Overall consumers would feel more confident about the authenticity of the products they are buying, which can stimulate the consumption of sustainable products.

The extent of benefits realizable through blockchain deployment in SCs depends on economic, technological and infrastructural developments. For instance, whereas companies such as Breau Veritas have emphasized on continual verification to provide highly reliable information about a product's history, such processes cannot be used in places that lack connectivity. Likewise, in the absence of advanced technologies such as machine vision to verify quality of products, farmers are forced to rely on quality assessment by officials of multinationals such as Nile Breweries.

Blockchain-led transparency can lead to positive social outcomes in SCs related to coffee, sea food and other industries. Blockchain implementation in SCs can thus improve the living standards and quality of life of low-income people. For instance, the fish and seafood SCs provide daily food and income for over 200 million people in Southeast Asia. Likewise, the coffee industry employs 25 million people directly, mostly in rural areas of developing countries. The global coffee industry is valued at US$200 billion. Coffee producing countries get only 10 % of this amount (Townley et al., 2018). Blockchain has the potential to stop unfair and unethical practices such as those noted in the opening example of this paper. For instance, Moyee's FairChain coffee aims to increase coffee producing countries' share to 50 % of the global coffee revenue (bext, 2018).

In some cases, benefits of blockchain deployment in global SCs only accrue to big multinationals. Cases such as those of BanQu indicate that systems and processes for tracking are often developed by keeping the needs of multinationals in mind. Collaboration among various stakeholders is needed to ensure that disadvantaged groups such as smallholders also benefit from blockchain deployment in SCs.

### 6.1. Practical challenges

While blockchain exhibits great technical potential, its deployment in SCs entail several practical challenges. First, facilitating and hindering conditions vary across jurisdictions (Queiroz & Wamba 2019). Among the hindering conditions, developing countries lack adequate absorptive capacity to benefit from blockchain due to the lack of competences and skills. For instance, Walmart needed to train about 100, 000 employees and suppliers to use its blockchain platform in China to make sure that enterprises or consumers can use it without additional costs (Zhuoqiong, 2019). Building and maintaining an advanced system such as an IoT platform (e.g., required by Bext360) would typically require large investments in software infrastructure and local skill development. Even if such systems are set up with outside help, small farmers cannot perform technical tasks such as troubleshooting and maintenance. The lack of user-friendliness of many blockchain apps further adds the complexity. A *Financial Times* journalist covering cryptocurrency reported that it took over an hour for her to figure out how she could gain access to her wallet. This was the case although she had used the same wallet before, which had migrated to a new app (Kaminska, 2019b).

Second, due to development costs and complexity, it is not currently practical to implement blockchain systems for low-cost products. Firms such as Alibaba and Walmart have limited blockchain deployment to products with high value or high information costs. The problem is worsened by the fact that developing countries lack local talent to develop blockchain applications. For instance, as of 2018, there were about 20 million software developers in the world and only 0.1 % of them knew about blockchain codes. No more than 6000 coders were estimated to have the levels of skill and experience needed to develop high-quality blockchain solutions (Suprunov, 2018). Likewise, out of India's 2 million software developers, only 5,000 were estimated to have blockchain skills (Agarwal, 2018). Other developing countries are in an even more unfavorable situation.

A third challenge is the lack of connectivity. For instance, in least developed countries (LDCs), which are low-income countries that perform poorly in human assets and face high economic vulnerability (https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-criteria.html), more than 27 % of the population does not have cellphones and more than 80 % lacks Internet access. This population is far from ready to adopt blockchain. As noted earlier, it will be extremely challenging to use systems such as Breau Veritas' continual verification and SCA's sensor-to-blockchain to capture SC activities of smallholder farmers that are not connected to the Internet.

Fourth, while blockchain systems are secure, their data, as is the case of other databases, are only as accurate as what is entered. For instance, in Walmart's case, details about products such as mangos and pork are entered by the farmers that grow or raise such products. There is always the possibility of data manipulation before entering into the blockchain system.

Fifth, serious concerns have been raised about costs in blockchain models that require paying with cryptocurrency (Kaminska, 2019a). The *Financial Times* journalist mentioned above reported that she transferred US$19 equivalent of bitcoin from one wallet to another. The fee to process the transaction was 109773 satoshis (US$3.10 based on Bitcoin's price for the day) (Kaminska, 2019b).

Sixth, facilitating and hindering conditions vary across industries (Queiroz et al., 2019). Low levels of economic activities in the agricultural sector are associated with thin markets, in which there are few buyers and sellers and few transactions in which blockchain-based applications can be used. Additional challenges include high transaction costs and risks, and high unit costs in the development of technological and physical infrastructures (Dorward et al., 2003). Due to these factors, being a part of blockchain systems set up by large organizations would involve significant costs and efforts for smallholder farmers. These farmers often need to travel long distances to take advantage of blockchain systems such as Bext360's kiosks and Nile Breweries' buying centers. For instance, farmers in Eastern Uganda are required to transport their crops to Nile Breweries' buying centers, which are located 10 kms or farther from their towns.

Seventh, there has been a lack of systems to accurately and fairly measure indicators such as the quality of crops before such data are entered into blockchain systems. For instance, to use the BanQu system Nile Breweries officials check for quality and other details before recording the data in blockchain (Equator News, 2019). One stated benefit of blockchain is that aggregators can no longer exploit farmers. However, the possibility of exploitation by large industrial buyers such as Nile Breweries cannot be ruled out. Machines can classify products and measure quality indicators based on objective characteristics. However, the low levels of economic activities and thin markets can make investments in technologies unattractive. In the absence of supporting technologies, potential benefits of blockchain cannot be fully realized.

### 6.2. Future research implications

Before concluding, we suggest several fruitful future research avenues. As discussed above organizations have set a number of sustainability goals to be achieved using blockchain (e.g., Moyee's goal to increase coffee producing countries' share to 50 % of the global coffee revenue) (bext, 2018). Consumers' higher purchase intention and willingness to pay more for products that are tracked with blockchain are a precondition to achieve these goals. Prior research has suggested that companies can obtain a price premium by using blockchain as a means to verify product quality and provenance (Cao et al., 2020). There is a need to extend such research to sustainability. Future research thus should look at whether consumers are willing to pay more for sustainably sourced products that can be traced with blockchain solutions. Researchers should also examine whether purchase intention and willingness to pay more vary across countries, consumers belonging to specific generations (such as baby boomers, the Millennials and Generation Z), other characteristics of consumers such as technological savviness and familiarity with blockchain-based services and applications and products (e.g., commodity versus branded).

Second, the work presented in this paper needs to be discussed in the context of CSR research in the developing world, which has been criticized for its failure to analyze the government's roles (Idemudia, 2011). Hamann (2004) argued that due to poor regulatory enforcement, CSR remains no more than a voluntary commitment in developing countries. In light of these observations, future research can examine blockchain's potential roles in bridging the enforcement gap and enhancing government capacities. The cases of Walmart and Provenance illustrate that blockchain systems make enforcement easier, stronger and more credible. One way to evaluate such impacts would be to compare CSR trends across industries with different degrees of blockchain use.

Finally, blockchain systems discussed in this article utilize diverse technologies such as machine vision, the IoT (e.g., Bex360), QR codes (e.g., Alibaba) and RFID tags (e.g., Provenance). Other technologies incorporated in blockchain solutions include satellite imagery and digital twins (Kshetri, 2021). Several categories of information collected and shared in such systems include environmental conditions (e.g., temperature and humidity), economic variables (e.g., earnings of SC participants), and personal information (e.g., identity). In order to provide a systematic understanding of these phenomena, future researchers might develop typology of indicators and sources of information in various blockchain systems used to promote sustainable SCs.

## 7. Concluding comments

Blockchain's deployment in SCs is still in a nascent stage but is maturing at a fast pace. Currently due to the lack of resources, blockchain's benefits to vulnerable populations, such as smallholder farmers are far from guaranteed. These participants lack relevant skills and face unfavorable conditions in terms of technologies, infrastructures, and market developments. Moreover, blockchain systems to track SCs that are initiated by multinationals are often designed to benefit themselves rather than less powerful participants such as smallholder farmers.

With increasing adoption in SCs in developing countries, blockchain, however, has a potential to promote sustainability. For instance, by monitoring production and distribution processes, blockchain can help ensure regulatory compliance. By providing access to detailed and verifiable information about products, blockchain can give consumers confidence regarding their sustainability concerns. With this technology the quality of environmental and social reports of companies can be increased. Blockchain-based traceability can be used to monitor and assess the quality of products, which can reduce costs associated with recall and wastage.

## Authorship statement

All persons who meet authorship criteria are listed as authors.

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