Blockchain systems and ethical sourcing in the mineral and metal industry: a multiple case study

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Abstract:

Purpose: The purpose of this paper is to examine blockchain's roles in promoting ethical sourcing in the mineral and metal industry. **Design/methodology/approach:** It analyzes multiple case studies of blockchain projects in the mineral and metal industry. **Findings:** It gives detailed descriptions of how blockchain-based supply chain networks' higher density of information flow and high degree of authenticity of information can increase supply chain participants' compliance with sustainability standards. It gives special consideration to blockchain systems' roles in overcoming the deficits in the second party and the third-party trust. It also demonstrates how blockchain-based supply chain networks include outside actors and configure the supply chain networks in a way that enhances the empowerment of marginalized groups. **Practical implications:** It suggests various mechanisms by which blockchain-based supply chain networks can give a voice to marginalized groups. **Originality/value:** It demonstrates how blockchain is likely to force mineral and metal supply chains to become more traceable and transparent.

Keywords: artisanal and small-scale miners | blockchain | dodd-frank wall street reform and consumer protection act | environmental | social and governance | supply chain networks

Article:

1. Introduction

A number of serious environmental, social and governance (ESG) issues have been identified in supply chains (SCs) in general (LeBaron, 2021) and the mineral and metal (M&M) industry SCs in particular (Lèbre *et al.*, 2020). Mineral extraction activities' adverse impacts include environmental degradation, exploitation of child workers, human rights violations, population displacement and violent conflicts (UNSDSN, 2016). Most serious ESG risks reside deeper down in the SC (Sedex briefing, 2013). These include artisanal and small-scale miners (ASMs) in Africa. Exposure to toxic pollution is reported to cause birth defects among the children of cobalt miners in the Democratic Republic of Congo (DRC), which is the world's biggest cobalt producing country (amnesty.org, 2020).

The wide media coverage has brought to light highly unethical practices in M&M extraction activities. This is especially true for cobalt. About 10–20% of lithium ion batteries consist of cobalt (Nelson, 2019). An electric car battery requires 10–20 kilograms of cobalt (Wolfson, 2019). About two-thirds of cobalt used in the world is mined from the DRC. There are reports that children as young as six work in the mines, who are exposed to unsafe working conditions. They are exposed to potentially life-threatening skin and respiratory toxicity (Taylor, 2020). The wages are as low as US$0.75/day. A large number of preventable deaths have been reported in the cobalt mining industry (Ledger Insights, 2020). Due to such issues, cobalt is also referred to as "blood cobalt" (LeVine, 2018). The proponents of blockchain believe that these issues are likely to be tackled with this technology (Bennett, 2019).

From the 2010s, regulators in Western countries have started responding to some of the serious ESG issues. For instance, the Dodd–Frank Wall Street Reform and Consumer Protection Act requires US companies to vet SCs. Countries covered under this legislation include the DRC and nine neighboring countries (Ayogu and Lewis, 2011). Section 1502 of the Act requires mining companies to disclose if they source conflict minerals: tin, tungsten, tantalum and gold (3TG) – from these countries (Mwai, 2018). The EU Conflict Minerals Regulation (EU Regulation No. 2017/821) was adopted in May 2017 by the EU Parliament and EU Council (European Union, 2017), which came into force in 2021. Importers of 3 TG are required to carry out due diligence on their SCs to ensure that they were processed responsibly (European Commission, 2017).

Despite these regulatory developments, addressing ESG issues in the M&M industry is not easy. The M&M industry SCs have unique, unusual and idiosyncratic characteristics. For instance, minerals and metals often change physical characteristics, chemical composition and other features along the SC. Commenting on the challenges involved in tracking tantalum, which is used for making capacitors for smartphones laptops and other devices, traceability-as-a-service (TaaS) provider Circulor CEO Doug Johnson-Poensgen put the issue this way: "This isn't a simple track and trace. It's complicated, because we start with ore and end up with smartphones. Food traceability is much simpler. A banana does not change into a diamond halfway through its journey to a consumer" (Hyperledger*,* 2019).

Blockchain has the potential to address many of the ESG issues in SCs. The EU has recommended that the use of technology such as blockchain be explored to enhance SC visibility (European Union, 2020). Emphasizing the seriousness and urgency of ESG issues in this industry and blockchain's potential, Everledger CEO Leanne Kemp said: "We saw that the next most potentially conflicted SC is going to be in rare earths and batteries. We're not interested in tracking lettuce. That's not where the world needs us to be" (Allison, 2020a).

Prior researchers have suggested that by making effects and results more transparent, a firm can signal the quality of standards and gain legitimacy from various stakeholders (Mueller *et al.*, 2009). Blockchain researchers have recently established that due primarily to its features such as decentralization and transparency, a rapidly emerging application of blockchain has been in verifying sustainability (Di Vaio and Varriale, 2020). Unsurprisingly the world's biggest companies from industries such as automobile, lithium ion battery and diamond manufacturing have implemented blockchain to track SCs. Despite the importance of understanding blockchain's roles in promoting sustainability in M&M SCs, prior research has done little to address this issue.

Researchers have also emphasized the importance of studying the roles of technological innovations in SC management (SCM). Bush *et al.* (2015) suggested scholars and practitioners to look at sustainability issues in global SCs in order to better understand the effectiveness of instruments used, analyze the sustainability impacts and examine the effects on various stakeholders.

Specifically, the need for more research has been emphasized in blockchain's potential to overcome challenges in the existing governance arrangements (Kshetri, 2021a). Such challenges include the standalone and discrete systems of SC governance with a low degree of integration with outside actors (Macdonald, 2007), and the lack or ineffectiveness of watchdog organizations to make sure that companies follow sustainability standards (Dietrich and Auld, 2015). There are also complaints that the existing governance arrangements have failed to close geographical, informational, communicative, compliance and power gaps (Boström *et al.*, 2015). These gaps have enabled the dominant groups to maintain their operation and authority (Miller and Bush, 2015). A related point is that socio-economic empowerment requires coordinated set of actions from a range of state and non-state actors beyond as well as within SC institutions, which is currently lacking (Macdonald, 2007; Kshetri, 2021b).

Finally, prior researchers have noted that while multinational corporations' (MNCs) corporate social responsibility (CSR) activities in developing countries have attracted increasing research attention, Africa has been relatively underrepresented in this research area. Moreover, existing studies about Africa have mainly focused on two biggest economies in the region: South Africa and Nigeria, which attract most of the foreign direct investment (FDI) and MNCs in Africa (Kolk and Lenfant, 2010).

M&M industries in less represented African economies such as Rwanda, the DRC and Sierra Leone have been picked up with enthusiasm by commercial organizations developing blockchain solutions to help MNCs track CSR performances. These adoption of blockchain is shaped by diverse motivations and circumstances. Blockchain's potential to address CSR issues in Africa has been identified as an area requiring further research **(**Kshetri, 2021b).

Although prior work has examined blockchain's roles in improving institutional governance by creating and maintaining distributed ledgers of information (Berg, 2017), in little research have scholars examined how this technology can help fight various gaps in the existing governance arrangements (Boström *et al.*, 2015) especially in the context of M&M SCs. By bridging these gaps, powerful and dominant groups' ability to exploit the disadvantaged group can be reduced (Miller and Bush, 2015) and socio-economic empowerment can be promoted.

In light of the above, in this article, we address two related research questions:

> *RQ1.* How can blockchain change the existing governance arrangements to mitigate various sustainability-related concerns facing the M&M industry SCs?

RQ2. How can blockchain-based solutions promote socio-economic empowerment among disadvantaged groups working in this industry?

We analyze multiple case studies of blockchain projects implemented in M&M SCs. This article contributes to the literature on socio-environmental sustainability in SCs by explicating how blockchain's key features such as decentralization, immutability and transparency can ensure firms' compliance with sustainability standards in M&M SCs and give more representation to and increases the power of marginalized groups.

The paper is structured as follows. We proceed by first providing a literature review. Next, we discuss methods**.** Then, we develop some propositions related to blockchain's roles in addressing various sustainability issues and empowering the marginalized groups in the M&M industry. It is followed by a section on discussion and implications. The final section provides concluding comments.

2. Literature review

2.1 Supply chain governance and current challenges

The term governance can be defined as a process by which an organization or a society steers, coordinates and manages itself (Norris, 2000; Paquet, 1999; Scholte, 2002). Prior research has suggested several strategies and governance mechanisms that firms can use to manage SC relationships and governance. Two categories of mechanisms are considered (Eisenhardt, 1985; Heide, 1994). First, a firm can select exchange partners that have the ability as well as willingness to support its strategy (Ouchi, 1980). For example, a company can require a potential contractor's participation in its formal qualification program. Second, incentive structures can be designed (Williamson, 1983) to reward desirable behaviors and penalize noncompliance (Wathne and Heide, 2004).

These are, however, easier said than done. In this section, we discuss various challenges that confront SCs.

2.1.1 Information, communications and knowledge gaps

Boström *et al.* (2015) have identified various gaps that hinder a responsible SC governance. The needs related to reliable, comprehensive, authentic and credible information about sustainability impacts at various phases of SCs are not fulfilled. These gaps are referred to as information and knowledge gaps. In SC relationships, it is a common practice for buyers to evaluate the operational performance of suppliers. The process is referred to as vendor rating (Luzzini *et al.*, 2014). Information required to perform vendor rating is unavailable for small vendors. Likewise, incentive structures do not necessarily translate into desirable outcomes. Researchers have suggested that labeling can be used as an important tool to enhance consumers' perception of a firm's sustainability practices (de Andrade Silva *et al.*, 2017). However, firms may use false labels by misusing labeling programs related to production, process standards and other aspects (Grote *et al.*, 1999). By exploiting the information asymmetry, manufacturers and retailers may provide false information about products (Sønderskov and Daugbjerg, 2011).

The problem is further exacerbated by geographical distances created by outsourcing activities. Due to the geographical distance between the locations of production and consumption of commodities, powerful stakeholders from the Global North cannot see, feel or understand the serious environmental and social impacts of production activities taking place in the Global South. This is referred to as geographical gaps, which is related to public ignorance of the social and environmental circumstances, which make public debate and opinion-formation about these issues difficult. There is also a lack of collaboration and coordination among participants in SCs. This leads to communication gaps (Boström *et al.*, 2015).

2.1.2 Implementation challenges

Standards that have been formulated and various sustainability principles and criteria that have been defined are not necessarily followed by SC participants. Ensuring SC participants' compliance with strict principles and guidelines is often a challenging task (Boström, 2015). These lead to compliance or implementation gaps. 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 sustainability practices (Kshetri, 2020).

2.1.3 Power and accountability issues

An unequal distribution of power among SC actors hinders the development of sustainable SC governance. Such gaps are known as power gaps. In an institutionalized relationship, when decision-makers exercise power and control over certain groups but are unwilling to fulfill their responsibility, a problem of "accountability deficits" arises in a governance system (Macdonald, 2007). When big firms use coercive power, less powerful actors such as small firms and workers may be left vulnerable (Forster and Regan, 2001). Some workers are forced to work in low-wage informal sectors.

2.1.4 Misleading persuasive practices

Several SC governance arrangements have been operating despite the lack of evidence that these arrangements have contributed to sustainability improvements (Miller and Bush, 2015). Firms continue to engage in unsustainable activities under the name of sustainability (Blühdorn, 2007). Various standards follow narrow definitions of sustainability, which tend to favor powerful stakeholders and fail to reflect the concerns of marginal groups (Bush *et al.*, 2015).

For instance, mining industry is responsible for over a quarter of global carbon emissions and has displaced communities that are vulnerable to climate change (London Mining Network, 2019). However, this industry cites projected critical metals demand and frames itself as an actor to fulfill the demand to justify new projects and attract investment by and framing (War on Want and London Mining Network, 2019). There are thus credibility or legitimacy gaps. Such gaps can be attributed to the creation of an illusion of improvement without being accompanied by real improvement (Egels-Zandén and Lindholm, 2015) and low degree of transparency (Mol, 2015).

2.1.5 Lack of connection with actors outside SCs

Current SCs fail to engage a wider set of actors and institutions. Initiatives such as the Fair Trade systems have been designed as standalone, discrete systems of SC governance that lack the wider components to connect actors outside SC institutions (Macdonald, 2007). Due to a low degree of integration with outside actors, such SC governance systems thus have limited ability to improve the wellbeing workers and producers (Macdonald, 2007). Watchdog organizations lack effectiveness to make sure that companies follow sustainability standards (Dietrich and Auld, 2015).

Such problems become even more complicated due to the plurality of unaccountable power (government, industry, etc.) that make decisions affecting disadvantaged groups such as workers and producers. In such cases, a decision-making unit has only partial control, and thus only partial responsibility for outcomes. Macdonald (2007) refers to this phenomenon as “structural disempowerment”, in which such groups are unable to advance their economic or social position because they are not able to increase control over key resources and opportunities. They also lack the ability to influence external decision makers to fulfill responsibility.

2.2 Some necessary conditions for responsible supply chain governance to empower marginalized workers

A more relevant question is: what are the necessary conditions that lead to the empowerment of marginalized workers and producers? Macdonald (2007) identifies three such conditions in the context of the global coffee industry for ethical consumption campaigns such as the Fair-Trade systems. First, relevant decision-makers in the global North must accept their expanded responsibility to address the disempowerment problem that has affected these disadvantaged groups. Second, institutional capabilities must be strengthened so that the decision-makers do everything that needs to be done in order to empower the marginalized workers and producers. Third, the marginalized groups must be given a voice and represented in decision-making processes so that they can exercise some control over the institutional transformation processes (Macdonald, 2007).

The above observation underscores the importance of changes at two levels to fight the disempowerment and marginalization of disadvantaged groups in this industry. First, interactions and relationships within the SCs themselves must be changed. Second, some mechanisms must exist to ensure the participation of outside actors.

Regarding the first condition, the choice of a governance models in a SC is a function of how various participants in the network are connected to each other and their relative power and position within the network (Oliver, 1991; Rowley, 1997). We look at two key SC characteristics: centrality and density. Centrality refers to an actor's position relative to others in the network. A high degree of centrality is associated with a more prominent intermediary position (Rowley, 1997). SC density provides a measure of how actors along the value chain are interconnected. In a high-density SC network with high number of connections among nodes, an actor will receive more attention from other participants. The sharing of information among participants would lead to increased monitoring of organizations (Neville and Menguc, 2006). Organizations thus face pressures to comply with stakeholder expectations.

In Vurro *et al.*'s (2009) typology of sustainable SC governance (SSCG) models, Acquiescent SSCG is of special interest because this approach corresponds to low centrality and high SC density and hence is compatible with blockchain. A high network density facilitates information flow and forces organizations to comply with sustainability standards in order to remain in the network (Frenkel and Scott, 2005; Roberts, 2003). Likewise, low centrality implies a higher degree of decentralization.

However, peripheral actors can comply with sustainability standards only when resources and competences are available (Jiang, 2009). In the absence of such supports, weak and peripheral actors cannot influence information flows, which would force them out of the network and attempts are likely to be made to conceal unsustainable and irresponsible practices (van Tulder *et al.*, 2009).

As to the second condition, a coordinated set of actions from a range of state and non-state actors beyond as well as within SC institutions are needed to improve the wellbeing of marginalized groups (Macdonald, 2007). Theoretically the problem of disempowerment can be addressed by reconfiguring responsibilities across a plurality of decision-makers within and beyond SCs. That is, partial and shared responsibilities should be appropriately allocated and coordinated. However, the initiatives taken so far have largely failed to develop transparent means to define the boundaries of partial responsibilities. There has also been a lack of institutional mechanisms to strengthen co-ordination (Macdonald, 2007).

There have been some encouraging developments with regard to the roles of actors beyond SCs in influencing ESG issues. In the past few decades, various social groups have responded to what they view as a "distorted and unjust" governance system (Macdonald, 2007). Global SCs thus have been subjected to intense criticism and recent works of social groups have focused on the harshness of working conditions.

2.3 Blockchain's roles in sustainable supply chain

An emerging application of blockchain has been in demonstrating sustainability (Di Vaio and Varriale, 2020; Kshetri, 2021b). Blockchain makes sustainability-related indicators transparent, quantifiable and more meaningful (Kshetri, 2018). Prior research has noted in combination with other technologies, blockchain can help firms achieve the triple bottom line (TBL) goals (Treiblmaier, 2019).

Blockchain's features such as decentralization and immutability make it an ideal tool to improve SC traceability and address various shortcomings of traditional SCs (Kim and Laskowski, 2018; Toyoda *et al.*, 2017). Immutable data related to nature, quality, quantity, location and ownership and other characteristics can play key roles in addressing such issues (Saberi *et al.*, 2018). While non-blockchain SC information systems can uniquely identify products they perform poorly in traceability. Traditional SC information systems suffer from data silos – some SC data are accessible by some participants but are isolated from others. To trace ingredients across multiple tiers of SCs, 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 another key mechanism by which blockchain affects sustainability. This technology can provide visibility and provenance and 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 the flow of transactions and information, which can help identify the weakest links and understand the degree and nature of risks (Min, 2019). All these can lead to a reduction in opportunistic behavior (Schmidt and Wagner, 2019) and, consequently address unethical behaviors of SC actors (Treiblmaier, 2019).

Blockchain can render some intermediary tasks redundant (Tönnissen and Teuteberg, 2020). Such disintermediation can transform SCs by making it possible to conduct transactions without relying on a third party's trust (Queiroz and Wamba, 2019; Queiroz *et al.*, 2020). Distributed trust based on the consensus of a network of participants can replace trust produced by third parties (Francisco and Swanson, 2018), which can help reduce transaction costs and facilitate market-oriented practices (Cole *et al.*, 2019; Schmidt and Wagner, 2019).

Blockchain can help increase the authenticity of product information provided to consumers, which can increase their confidence about the product (Nikolakis *et al.*, 2018). Blockchain thus facilitates product traceability, which increases SC transparency and enhances consumers' perception of a firm's sustainability practices (Hald and Kinra, 2019). 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 order to punish unfair practices, individuals are willing to give up some monetary benefits (Camerer and Thaler, 1995; Roth, 1995). When there is the possibility that unfair behaviors lead to punishment, firms are less likely to engage in such behaviors. A practical challenge, however, is that it is often difficult to assess the fairness of some participants' behaviors. Blockchain-based transparency can expose unfair practices.

The discussion above indicates how blockchain can enhance SC sustainability by facilitating product traceability, improving the governance structures in SCs, helping increase the authenticity of product information and replacing some intermediary tasks. However, no blockchain study focusing on sustainability has yet looked directly at M&M SCs. Valuable insights can be gained by considering how these mechanisms apply in M&M SCs, which are more complex than SCs of most other industries.

3. Methods

Yin (1989) argues that case study methods are epistemologically justifiable when research questions focus on reasons behind observed phenomena, when behavioral events are not controlled, and when the emphasis is on contemporary events. This study satisfies these criteria since blockchain deployment in SCs is in an early stage of theoretical development, especially in the context of the developing world.

The approach of this paper thus involves studying multiple cases of blockchain projects in the M&M industry to build theory (Eisenhardt and Graebner, 2007; Kshetri, 2016, 2021b). We selected only cases for which sufficient information could be obtained from secondary resources. Such an approach can be justified since there has been extensive media coverage of blockchain. Note that archival data is among a variety of recognized data sources for case studies (Eisenhardt and Graebner, 2007).

Following Eisenhardt (1989), we selected four cases by combining two approaches: extreme and diverse methods (Seawright and Gerring, 2008). In the extreme method, cases with extreme values on the independent (X) or dependent variable (Y) of interest are selected (Seawright and Gerring, 2008). One of the independent variables is characteristics of SCs.

The cases we selected are extreme because they are among the earliest blockchain adopters in M&M SCs. We started with the biggest companies in the SCs of the M&M industry. The world's biggest diamond company is Russia's Alrosa, followed by South Africa's De Beers Group. Both have adopted blockchain. For instance, Alrosa teamed up with Everledger to launch a diamond-focused retail mini-program with Chinese social media and mobile payment platform WeChat. Diamonds from Alrosa enable full traceability.

Among minerals, cobalt has attracted the most scrutiny. We thus focused on cobalt SCs. On a global basis, the leading use of cobalt is in rechargeable battery electrodes (usgs.gov, 2020). We thus looked at blockchain adoptions among relevant players. In the lithium-ion battery industry, two biggest companies are China's Contemporary Amperex Technology Co. Limited (CATL) and South Korea's LG Chem. LG Chem is a member of the Responsible Sourcing Blockchain Network (RSBN), which is an industry collaboration that aims to support sustainable and responsible sourcing and production practices. Circulor operates a blockchain platform across CATL's SC (Rolander, 2019).

The top four automotive companies by revenue in 2019 were Volkswagen, Toyota, Daimler and Ford. Volkswagen and Ford are RSBN members. Other RSBN members include IBM, Huayou Cobalt, RCS Global, Fiat Chrysler and British-Swiss commodities trading company Glencore. Volvo is a participant in CATL's SC that Circulor operates.

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

To achieve diversity, we selected cases by using different combinations of the following: (a) Degree of custom made elements; (b) Industry (case number in square brackets []). Table 1 presents classification of cases. We explain the rationale below:

Table 1. Classification of cases in terms of the industry and the degree of custom made elements in the solutions

Industry → / Degree of custom made elements ↓	Minerals	Gems and precious metals
High (built by a firm or a consortium of SC entities)	RSBN [1]	De Beers [2]
Low (provided by a technology company)	Circulor [3]	Everledger [4]

3.1 Degree of custom-made elements

Some platforms have been initiated by trading partners belonging to the same SC or by individual companies. They have deployed custom-built platforms for specific purposes. RSBN has diverse entities in a lithium-ion battery SC such as a cobalt manufacturer, a lithium ion battery manufacturer and automobile companies.

In other cases, generic platforms developed by blockchain companies have been used. Another relevant dimension of diversity concerns cases involving private and public blockchains, which allowed us to examine different blockchains' deployment. For instance, De Beers' Tracr uses public blockchain Ethereum and the rest use private blockchains.

3.2 Industry

Materials in SCs pose different levels of difficulties in implementing blockchain. It is simpler to track diamonds compared with ores such as coltan. Each diamond cut has unique elements, which can be translated into data attributes to ensure the immutability of every transaction (Forbes Africa, 2018). On the other hand, coltan would need to be refined to produce tantalum. Minerals relying on smelting and refining are more difficult to track. The refining process increases the risk of clean batches of being mixed with other batches containing conflict minerals (Uwiringiyimana and Lewis, 2018). The complexity also increases as the number of players in a SC increases. The global cobalt SCs can be as deep as 13 layers (Del Castillo, 2017).

Table 2. A brief description of the selected cases

Case	Blockchain used/key users	Sample blockchain projects/performance indicators
RSBN	Hyperledger Fabric overseen by RCS Global	2019: initial test: 1.5 ton batch of cobalt was tracked from Huayou's mine site in the DRC to refinement facility in China, then to LG Chem's cathode and battery plant in South Korea, and finally to a U.S.-based Ford plant
Circulor's traceability-as-a-service (TaaS) solution	Oracle's blockchain platform (OBP)	November 2019: Volvo, CATL and other participants recorded about 28 million material scans and other production events per month
De Beers	Tracr was developed with Boston Consulting Group's Digital Ventures using Ethereum	Early 2020: more than 30 participants, tens of thousands of precious stones are registered per month on Tracr
Everledger	IBM's TrustChain platform built on Hyperledger Fabric	April 2019: recorded the origins of about 2.2 million diamonds

Table 2 provides a brief description of the selected cases.

3.2.1 Brief discussion of the selected cases

3.2.1.1 De Beers' solutions

De Beers' Tracr was launched in 2018 to track diamonds as they move from the mine to cutter and polisher, and then to jewelers to establish provenance, authenticity and traceability. By 2020, more than 30 participants used Tracr (Sabine, 2019).

Tracr aims to develop a "Global Diamond ID". Diamonds undergo 3-D scans when they are mined, cut, polished and sold (Debter *et al.*, 2020). It uses data involving 200 characteristics to uniquely identify each diamond (Bates, 2018).

De Beers has also launched the GemFair program to log diamonds produced by ASMs. In the first phase, De Beers trained ASMs in 16 sites in Sierra Leone. The training program focuses on digitally tracking of diamonds. By April 2019, De Beers extended the pilot to 38 additional sites.

Among the major requirements, ASMs need to identify the worst forms of child labor and address them. Compliance is ensured through first party (e.g. a member completes a self-assessment workbook), second-party (GemFair's monitoring of sites bi-annually) and third-party (commissioning a third-party assessment of a sample of mine sites twice a year) verifications.

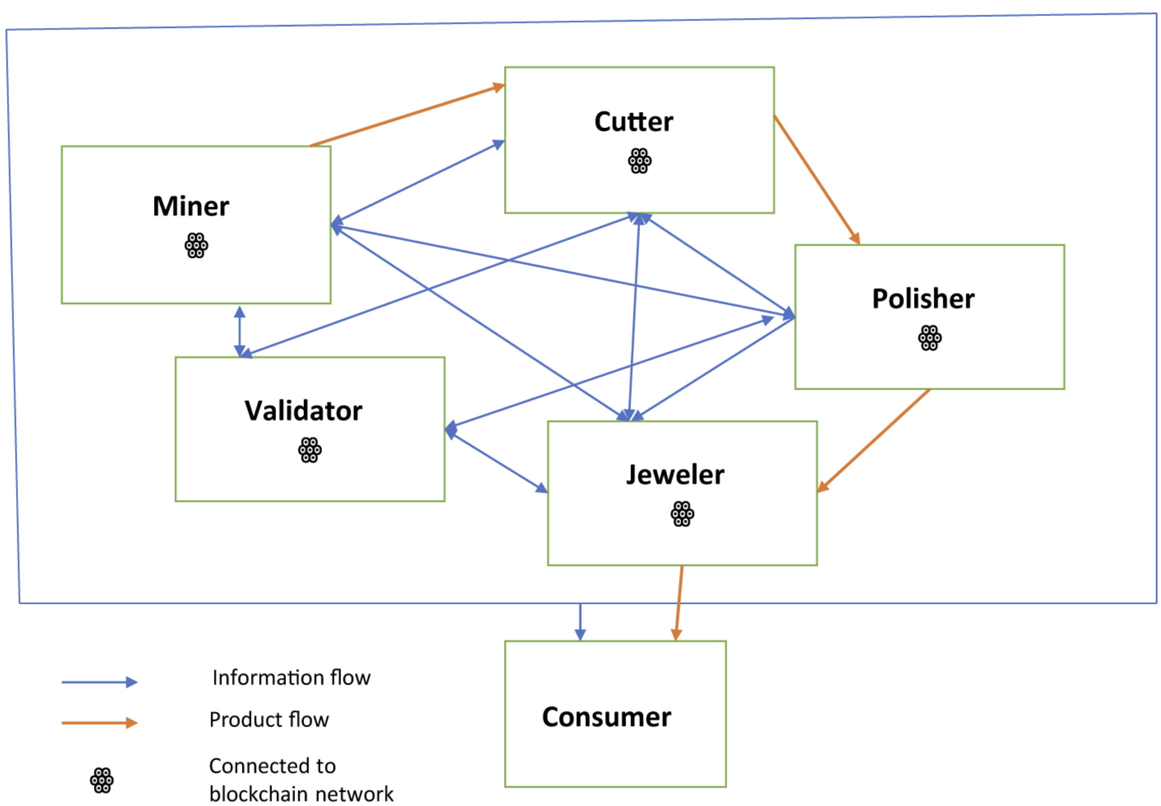

Figure 1. Tracing a diamond in a supply chain with blockchain: an illustration

Tracr identified three major challenges that must be addressed for tracking diamonds: (a) determining the features to uniquely identify a piece of rough diamond; (b) determining the features to uniquely identify a piece of polished diamond; and (c) matching a polished piece with the rough piece it comes from. The last step is arguably the most challenging one. It was reported that Tracr successfully tracked 200 different diamonds in its pilot phase (Bates, 2018). The company claims that it uses state of the art AI tools to observe a diamond to determine its journey (https://www.tracr.com/).

Each organization involved signs into a blockchain platform (Figure 1). De Beers' program records GPS locations for each diamond found, which is then placed in a tamper-proof QR-coded bag (Belton, 2019). GemFair provides a tablet for a mine site to log in the app, which also functions offline. However, it must be connected to the internet for records to be stored in the system. After this step, the raw diamonds move on to the next stage (Hill, 2018).

3.2.1.2 Everledger

London-based technology enterprise Everledger's blockchain-based solution was first used for tracking rough-cut diamonds. Everledger uses IBM's TrustChain platform built on the Hyperledger Fabric, which a modular blockchain system that allows organizations to develop products, solutions and applications based on blockchain. Key components such as consensus and membership services work on a plug and play basis. It thus allows organizations to conduct confidential transactions without a central authority.

Everledger gives unique cryptographic ID to each piece of diamond based on more than 40 attributes. The cognitive analytics systems utilize AI to cross-check data related to regulations, relevant records, SC and IoT to ensure that the gems from conflict regions do not enter the SC (Thibodeaux, 2018). All permissioned parties have access to data.

As noted, a necessary condition for empowering marginalized groups would be to give them a voice and representation (Macdonald, 2007). In this regard, Everledger and Swiss-based jewelry retailer Gübelin provide a no-cost solution to track colored gems produced by ASMs (Cholteeva, 2019).

3.2.1.3 The RSBN

The RSBN platform is built on Hyperledger Fabric and is overseen by responsible-sourcing group RCS Global. The project has been implemented in southern Congo (Ross and Lewis, 2019). When cobalt is bagged and tagged, the miner (Huayou) adds data. For successive stages and key events such as smelting and refining, data related to inputs and corresponding outputs are added. New pieces of information related to shipping and other details are added from partners along the SC route. The record is automatically updated each time a transaction is added and made visible to the permissioned participants in real time (Devanesan, 2020). The idea is to allow regulators as well as end users to verify the data (Baydakova, 2019). In this way, this solution addresses a major concern inherent in modern SCs that they are designed as standalone and discrete systems that fail to connect actors outside SC institutions (Macdonald, 2007).

In an initial test, the RSBN demonstrated the use of blockchain to track cobalt produced at Huayou's mine site in the DRC. The flow of 1.5-ton batch of cobalt was traced through mines in the DRC which was refined in China. The refined mineral was then sent to LG Chem's cathode and battery plant in South Korea, and then to a US.-based Ford plant.

3.2.1.4 Circulor

Circulor utilizes Oracle's blockchain platform (OBP), which is based on Hyperledger Fabric. OBP sets up, manages and maintains the blockchain platform for enterprises.

OBP is combined with AI algorithms to perform due diligence, identify data anomalies and actions that need further investigation. Data captured include the ore's origin, attributes (e.g. weight and size), the chain of custody and information to establish SC participants' actions comply with globally recognized SC guidelines (Wolfson, 2019).

The application's field test was carried out for Tantalum mined in Rwanda and Cobalt used by Volvo Cars (Hall, 2019). Circulor teamed up with the government of Rwanda and Power Resources Group (PRG), which has mining and refining operations in Rwanda and Macedonia (Côme Mugisha, 2019). As of November 2019, Volvo, CATL and other SC participants recorded 28 million material scans and other production events per month (Wolfson, 2019).

The combination of AI and blockchain can be an effective way to address *i*nformation and knowledge gaps. There is the lack of reliable, authentic and credible information about sustainability impacts of SCs. Reliability and authenticity of data in the first mile, which is the most crucial step in assuring the quality of the ore (Brugger, 2019), are a key challenge. For instance, blockchain systems can be corrupted if the government agents tagging bags collude with smugglers and enter incorrect data. In Circulor's system, miners enter the data, whose identities are confirmed with facial recognition software (Ross and Lewis, 2019).

4. Findings and propositions

The cases discussed above illustrate the roles of blockchain systems in identifying, tracing and tracking relevant information in M&M SCs. The systems ensure that data are shared in a tamper-proof way and are accessible to relevant parties, which make it possible to trace products across multiple tiers of a SC.

Blockchain systems to trace metals such as diamond are simpler compared to minerals such as cobalt. For instance, Everledger [4] stores diamonds' unique identities derived from more than 40 attributes. Minerals such as cobalt traced by RSBN [1] and Circulor [3] go through complex stages such as smelting and refining, which makes it difficult to adopt a foolproof procedure.

In each case, major technologies other than blockchain are an integral part. They include OBP's AI algorithms to perform due diligence in Circulor's system, IBM's exploration of chemical analysis using AI to pinpoint the origin of cobalt in RSBN, AI tools to observe a diamond to determine its SC journey in De Beers' system and Everledger's use of AI to cross-check data related to regulations, relevant records, SC and IoT to ensure that the gems are not from conflict regions (Thibodeaux, 2018). In Table 3, we present some of the roles of blockchain and other major technologies in enhancing traceability.

Table 3. The uses of blockchain and other major technologies in identifying, tracing and tracking relevant information

Technology → Identifying, tracing and tracking information about ↓	Blockchain	Other major technologies
People and organizations	Cryptography-based digital signatures verify identities of participants. Provides a foolproof method of verifying certain sustainability indicators such as payments made to miners' wallets	Circulor: facial recognition software to confirm the identities of miners; machine learning and aerial imagery to determine whether a mining company has employed children in its operations; satellite data to verify that a mine is working. OBP is combined with AI, which checks if SC participants' actions comply with globally recognized SC guidelines.
Minerals and metals	Data are stored and shared in a tamper-proof way and are accessible to all relevant parties (e.g., Everledger stores diamonds' unique identities that are derived from more than 40 attributes).	IBM's planned AI solution: chemical analysis to pinpoint the origin of cobalt. Tracr: AI tools to observe a diamond to determine its SC journey (https://www.tracr.com/) De Beers: GPS locations for each diamond found Circulor: smartphones with GPS capability to pinpoint the location where the ore was tagged

4.1 Patternmatching theory and data

Prior researchers have emphasized the importance of "patternmatching" theory and data and suggested that propositions need to be consistent with the selected cases (Eisenhardt and Graebner, 2007). Table 3 provides a theory summary to understand the roles of blockchain in monitoring and enforcing sustainability standards in the M&M industry.

4.2 A decentralized network with a high supply chain density

A SC system can be viewed as trusted relationships that are maintained with various "ledgers" (Berg *et al.*, 2018; Casey and Vigna, 2018) (see Table 4). In the non-blockchain world, these ledgers and records are maintained by centralized entities (Abadi and Brunnermeier, 2018). As an institutional governance mechanism for creating and maintaining distributed ledgers of information (Berg, 2017), blockchain turns centralized management of records upside down (Allen *et al.*, 2019). In De Beers' system [2], for instance, all relevant participants such as miners, cutters, polishers, the validator and jewelers receive information about all transactions**.** In this way, blockchain-based SC models are characterized by low centrality and high SC density and thus closely resemble the Acquiescent category in Vurro *et al.*'s (2009) typology of SSCG models. Due to a high degree of information flow and a low dominance of a given actor, SC participants are likely to comply with sustainability standards. The tendency of manufacturers and retailers to exploit the information asymmetry to increase profits by providing false information (Sønderskov and Daugbjerg, 2011) can be addressed with blockchain. The above leads to the following:

> *P1.* SC networks that use decentralized blockchains can reduce centrality and increase density, which increase SC participants' compliance with sustainability standards.

Table 4. Patternmatching theory and data Examples [Case No.]

Reduce centrality and increase density, which increase SC participants' compliance with sustainability standards (P1)	De Beers [2]: all relevant participants such as miners, cutters, polishers, the validator and jewelers receive information about all transactions
Enhance the second party trust and enforcement in SC partners' sustainability efforts (P2)	De Beers [2]: records GPS locations for each diamond found
Enhance the third-party trust and enforcement, to increase the compliance with sustainability standards. (P3)	Circulor [3]: monitors mines in Rwanda using smartphones with GPS capability, the coordinates the mine's operations and its historical production are entered in the system and satellite data is used to verify that the mine is working
Include outside actors, which can enhance the empowerment of marginalized groups (P4)	RCS Global is the data validator of RSBN [1] Everledger [4] has included underwriter Labs (ULs) to increase the confidence of the TrustChain platform Everledger's [4] Diamond Time-Lapse Protocol allows customers to view the complete provenance report of their purchased diamonds
Reconfiguration of SCs, resulting in increased power for marginalized groups (P5)	Circulor [3] plan to train and improve its machine learning models to distinguish between children and adults with a high level of accuracy using aerial imagery data: no need to rely on data from government agencies and other sources for human rights and child labor problems
Giving more representation to and increases the power of marginalized groups (P6)	Circulor's [3] easy to use mobile app and De Beers' [2] GemFair's tablet are used by ASMs to enter the data themselves and influence information flows, which would make it difficult to conceal unsustainable and irresponsible practices (van Tulder *et al.*, 2009).

4.3 Impacts on trust and enforcement

Zucker (1986) identified three ways to produce trust: (1) institution-based (linked to government bureaucracies and other formal mechanisms, trade associations and professions); (2) process-based (produced from the engagement in trustworthy relationships); and (3) characteristic-based (generated by identifiable attributes linked with trustworthy behaviors).

There are three types of trusts and enforcements: first-party (trust in self), second-party and third-party. Of special relevance are the second-party and third-party trust. In Zucker's classification above, (1) can be mapped to the third-party trust and (2) and (3) can be mapped to the second-party trust.

Regarding (1), institutional trust-producing structures are not well-developed in many resource-rich African countries. For instance, due to corruption and political patronage, there is a low degree of trust in the DRC's government and its institutions. Seay (2012) comments on the situation in the eastern DRC: ".. it is possible to bribe almost every border guard, customs official, and immigration authority in the region. These officials are not paid regular salaries and are dependent on money they can raise through bribery and the imposition of made-up fees to provide for their livelihoods" (p. 19). In general, third-party enforcement mechanisms, which are often formal coercive measures by the state, have been relatively ineffective. This increases the importance of other types of trust and enforcement.

Regarding process-based trust, there have been instances of untrustworthy transactions. Most companies rely on a paper-based certification. UN experts have documented cases in which tags used to identify clean minerals were stolen in eastern Congo and sold to smugglers. Ore from blacklisted mines was sold as responsibly sourced (Ross and Lewis, 2019). The artisanal extraction of cobalt in the DRC has also been linked to toxic harm to vulnerable communities (Nkulu *et al.*, 2018). There is thus the lack of process-based trust due to some actors' untrustworthy behaviors.

The above problem is the result of the lack of the second-party trust. The questions here include who the party is and whether they behave in a way that is mutually agreed upon.

The lack of institutional trust and process-based trust means that firms in the African metal and mineral industry are essentially left with only characteristic-based trust. That is, blockchain-based SCs to track minerals are viewed as having attributes that are linked with trustworthy behavior. The challenges related the second- and the third-party trust can potentially be addressed by blockchain.

There are, however, some limitations of blockchain. Data in blockchain systems are only as accurate as what is entered. As noted above the lack of trust and lack of trustworthy behavior can be a problem with upstream firms in the M&M industry.

While firms need to select potential SC partners with the ability and willingness to engage in sustainability practices, it is not easy to determine the authenticity of information provided (Sønderskov and Daugbjerg, 2011). A key question that must be addressed in order for blockchain systems to work is thus: How can the accuracy of what is entered in the blockchain system be ensured? The deficits in the second party trust can be reduced by using advanced technologies. Knight (1940) views applying the methodology of natural science as a better way of arriving at a truth rather than depending on sense observation such as our subjective perception of time and space.

The problem of trust deficit can thus be dealt with using a methodology based on natural science. For instance, the position information for the location of extraction sites can be determined from various sources. De Beers'[2] program records GPS locations for each diamond found. Likewise, in Circulor's system [3] in Rwanda, smartphones with GPS capability are used to pinpoint exactly the location where the ore was tagged (Ross and Lewis, 2019).

Another important consideration is that blockchain systems represent trade-off between efficiency and trust. Private, permissioned blockchains remove the need for slow and cumbersome verification process that completely decentralized blockchains such as bitcoin use. Private blockchains such as Hyperledger Fabric used by RSBN [1], Circulor [3] and Everledger

[4] are thus much faster and more efficient than the public, permissionless systems and thus are better suited in the context of SC transactions that require handling large volumes of data in real time (Burns, 2016). There is, however, a risk that a large player can create a monopoly on the global mineral SC tracking initiatives using private, permissioned blockchains (Gleeson, 2019). Public blockchains could provide a safeguard against such risks. For this reason, public blockchain would be viewed as more justifiable than private permissioned blockchains if the trust issue is extremely critical.

In a blockchain platform initiated by an individual company such as De Beers [2], which is also used by its competitor Alrosa, a few additional considerations need to be addressed. In a situation such as this, there is, what is referred to as an “asymmetrical data problem” (Thompson, 2020). The idea is that the company which owns the platform is perceived to derive more value from data exchanges in the platform, especially if the platform is based on a private, permissioned blockchain. Compared to solutions provided by a third party technology company [e.g. 3 and 4] or developed by a consortium [1], private blockchains' trust producing roles are more problematic when such platforms are controlled by a private company [2].

A key mechanism to manage SC governance is to design incentive structures (Williamson, 1983) to reward desirable behaviors and penalize noncompliance (Wathne and Heide, 2004). A challenge is to assess (non-)compliance. For instance, when minerals are smelted, they are often combined with metals from various sources. This increases the difficulty of tracking. Companies are looking at advanced technological solutions such as AI to prevent such practices. It was reported that IBM was exploring the possibility of performing chemical analysis using AI to pinpoint the origin of cobalt. The goal is to ensure that “clean” batches of cobalt are not smelted with unethically sourced minerals.

Such systems have been or are being undertaken to track people and organizations as well. For instance, when a registered mining company with a concession applies to use Circulor's [3] mine-to-manufacturer traceability, the coordinates the mine's operations and its historical production are entered. Satellite data verify that the mine is working (Burbidge, 2019). Circulor's plan is to use machine learning and aerial imagery to ensure that child labor has not been used. Based on above discussion, the following propositions are presented:

> *P2.* Blockchain systems are likely to enhance the second party trust and enforcement in SC partners' sustainability efforts.
>
> *P3.* Blockchain systems are likely to enhance the third-party trust and enforcement, which increase the compliance with sustainability standards.

4.4 Blockchain-led expansion of supply chain networks with reconfiguration of responsibilities

A drawback of governance arrangements in modern SCs is their standalone and discrete nature with a low degree of integration with outside actors (Macdonald, 2007). Blockchain-based systems are superior because outside actors are connected. For instance, TrustChain, which is used by Everledger [4], has included Underwriter Labs (UL) as an independent verifier (Hill, 2018). Since the information is verified by a third-party such as UL, it strengthens the authenticity of information. Likewise, Everledger's [4] Diamond Time-Lapse Protocol allows customers to view the complete provenance report of purchased diamonds (IDEX, 2018). In the same vein, RCS Global is the validator of the RSBN [1]. Also, the idea behind RSBN is also to allow regulators and end users to verify the data (Baydakova, 2019). Government officials put barcoded tags on the sacks of tantalum ore (Ross and Lewis, 2019). The addition of such nodes leads to further increase in SC density and SC participants' propensity to comply with sustainability standards. The preceding discussion can be summarized as:

> *P4.* Compared to non-blockchain networks, blockchain-based SC networks are more likely to include outside actors, which can enhance the empowerment of marginalized groups.

Blockchain can fulfill the necessary conditions for sustainable SCM that can empower the marginalized groups. For instance, one way to improve accountability mechanisms would be to disaggregate responsibilities between relevant decision-makers and coordinate decision making processes to achieve a given goal (workers' and producers' well-being) (Macdonald, 2007). The required coordination among the different actors within and beyond the SC institutions can be achieved by combining blockchain and other technologies.

One way to address the problem of disempowerment is to reconfigure the allocation of responsibility (Macdonald, 2007). Due to corruption and poor enforcement of the rule of law, the governments of mineral and metal originating countries such as the DRC have not been able to deal with human rights and child labor problems. These governments do not have the same incentives and pressures to be accountable as Western MNCs.

From the perspective of Western MNCs, one way to deal with enforcement challenges and the third-party trust deficit would be to take enforcement responsibility themselves. In July 2020, Volvo Cars' venture capital investment arm Volvo Cars Tech Fund and three other investors announced an investment in Circulor [3] (Volvo Cars, 2020). Circulor plans to use the funds to improve its machine learning models so that they can distinguish between children and adults. The plan is to use aerial imagery to determine whether a mining company has employed children. In this way, the enforcement responsibility shifts from the local government to the blockchain system. Blockchain and other technologies can help redesign the responsibilities of various actors to more effectively address the challenges of disempowerment. It is proposed:

> *P5.* Blockchain can reconfigure SCs, resulting in increased power for marginalized groups.

4.5 Measures for giving voice to marginalized groups

In the governance systems of traditional SCs, weak and peripheral actors' lack of voice and resources is among the main reasons that would prevent them to comply with sustainability standards (Jiang, 2009; Macdonald, 2007). Some of the key challenges can be overcome by using blockchain-based institutional governance mechanism which, as noted earlier, is based on the creation and maintenance of distributed ledgers of information (Berg, 2017). For instance, in Circulor's [3] system, the details of the materials are entered by ASMs by registering on the system (Bennett, 2019). Its application has two interfaces: a) Mobile apps for checking IDs, scanning QR codes at checkpoints, and downloading documents; b) Desktop versions for corporate offices to provide SC visibility and provide answers to queries. The system databases are hosted in Oracle Cloud and Amazon Web Services (Hyperledger, 2019). Specifically, ASMs use a mobile app, which is free and is easy to use (Bennett, 2019), whereas companies further up the SC pay and use more complex interfaces.

The process begins with a facial recognition. There are three buttons on the miners' app. A step-by-step process is presented by clicking “Start”. Small mining companies do not see an increase in workload. The final step of that registration is that the regulators approve it. Likewise, GemFair provides a tablet for mine sites (Hill, 2018).

ASMs thus have access to relevant resources and competencies, which prior researchers have found to influence their likelihood to comply with sustainability standards (Jiang, 2009). Moreover, weak and peripheral actors such as ASMs influence information flows, which would make it difficult to conceal irresponsible practices (van Tulder *et al.*, 2009). The most important is that the marginal groups such as miners are a part of the network. These groups thus get a voice and are represented in decision-making processes, which is a key step in the institutional transformation processes (Macdonald, 2007). The above discussion leads to the following proposition.

> *P6.* Blockchain-based SC networks can give more representation to and increase the power of marginalized groups.

5. Discussion and implications

Blockchain is playing a significant role in ensuring and verifying certain sustainability indicators. There have been concerns about affordability and effectiveness of non-blockchain traceability solutions such as the Kimberley Process used to trace the flow of diamonds and ITSCI traceability system for conflict minerals. For instance, the Kimberley Process Certification Scheme (KPCS) has not been able to address concerns for producers, sellers and buyers (Sabine, 2019). A case in point is Sierra Leone, which is a signatory to the KPCS. However, the scheme has failed to stop diamond smuggling. One estimate put the proportion of illegal diamonds in Sierra Leone at least 50% (Maconachie and Binns, 2007). Likewise, complaints regarding lack of affordability and opacity of non-blockchain solutions used in tracing conflict mineral SCs have been pointed out by regulators and other actors (Bizimungu, 2019). Blockchain-based solutions seek to alleviate these drawbacks.

Sauer and Seuring (2019) noted that most sustainability issues need to be addressed in the upstream SC and technologies used in the current multi-tier sustainable SCM practices are insufficient. This paper provided insights into how blockchain's key features such as decentralization, immutability and transparency can address some of the challenges especially those related to socio-environmental sustainability such as reducing human rights violations and enhancing working conditions.

Prior research has noted that blockchain systems allow consumers to verify sustainability-related information themselves (Saberi *et al.*, 2018). Solutions such as Everledger's Diamond Time-Lapse allow customers to view the complete provenance report of their purchased diamonds. Since consumers are increasingly concerned about the sustainability standards of products that they are consuming (Kshetri, 2021b), companies are likely to take actions to increase welfare of marginalized groups in an attempt to gain legitimacy from consumers.

The roles of blockchain and other accompanying technologies are especially crucial and important in second-party and third-party trust. Many of the activities are currently performed by humans such as government agents, inspectors and certifiers. The verification processes have several challenges. It is envisioned that in the future, AI and other systems, and networks will be deployed, which autonomously sense, analyze information and take action (Sulkowski, 2019).

A common application of AI in Circulor's OBP [3] and Everledger's [4] platform has been in performing due diligence such as cross-checking data related to regulations. However, different AI-based tools have also been created. For instance, IBM is developing AI tools to perform chemical analysis to pinpoint the origin of cobalt in RSBN [1] (Lewis, 2019). No equivalent tools exist or have been planned for the diamond industry.

Among major drawbacks of most blockchain networks are their inability to link a physical product to what is recorded on the ledger. While there is no central intermediary in a blockchain network and the network of participating users relies on a set of predefined rules and agrees on the validity of what is being added to the ledger, the agreement does not mean that the real truth is verified. More specifically, the majority of the nodes in the network need to reach for a consensus to do so. Knight (1940) notes the limitation of such an approach: ".., a consensus regarding truth is itself by no means a "mere" (undisputed) fact. It rests upon value judgments as to both the competence and the moral reliability of observers and reporters. (It is no matter of a majority vote!).." (Knight, 1940, p. 7). While the real truth is impossible to verify directly, by combining blockchain with other technologies, parties in a SC can try to reach as close to the real truth as possible.

In order to signal the quality of standards and gain legitimacy from various stakeholders, firms need to make effects and results more transparent (Mueller *et al.*, 2009). Blockchain-based solutions increase access to reliable information, which increases transparency.

The theory presented in this paper provides an approach to answering our research questions posed earlier. Regarding RQ1, we provide some insights into blockchain's roles in challenging the existing governance arrangements. A blockchain-based SC network is characterized by a high network density, which facilitates information flow (Frenkel and Scott, 2005; Roberts, 2003). Everledger's chief experience officer noted: "This [developing world] is actually where I think blockchain has a lot to offer rather than less. Instead of relying on a single endorsing party that could be compromised, we can send information across the network and search for providers and data that substantiates different aspects and that gives a more complete picture of truth and trustworthiness" (Vella, 2020).

Blockchain makes it difficult to hide unsustainable practices. For instance, some firms use evidence based on narrow criteria of sustainability to justify unsustainable practices (Bush *et al.*, 2015). Glencore reported that in 2019, it spent US$90 million on community development programs (Environmental, Social and Governance data, 2019), which was 0.04% of its revenue (statista.com, 2019). It performs poorly on most other ESG issues. Glencore reported that seventeen people were killed in its operations in 2019 (glencore.com, 2020). In blockchain-based solutions, machine learning algorithms can analyze aerial and satellite images of mine sites and flag hazardous conditions. It is thus possible to know ESG violations before they occur.

As to RQ2, blockchain-led accountability, and transparency lead to the empowerment of disadvantaged groups. Being accountable means that when one actor exercises power over another, the actor is required to be responsive to the needs of those over whom the power is being exercised (Macdonald, 2007). In a non-blockchain world, there is often no way to be certain as to whether responsibilities have been fulfilled. Blockchain-led transparency can force companies to be more accountable. If companies know that their activities are being observed, they may follow sustainability principles and meet the defined criteria. In this way, compliance or implementation gaps can be bridged.

Despite the emphasis on creating pluralistic stakeholder value by engaging with all stakeholders (Schormair and Gilbert, 2021), marginalized groups are excluded from decision makings. This article described various mechanisms to empower marginalized groups by ensuring their access to critical resources and competencies to influence information flows. It is unreasonable to expect that blockchain solutions can be sent into rural Africa for artisanal miners (Early, 2019). However, easy to use and free solutions such as Circulor's mobile app for ASMs are tackling the issues of power, voice and representation. SC participants alone, however, can do little to enhance the wellbeing of marginalized groups. They need to collaborate with other stakeholders to ensure that disadvantaged groups are empowered. Blockchain-based business models are designed to facilitate collaboration among SC participants and key outside actors.

5.1 Future prospects

Blockchain based solutions' future potential is even greater. Solutions relying on blockchain and cryptocurrency are developing at a rapid pace. For instance, solutions are being developed in which if a mining company claims that living wages are being paid to its miners, the accuracy and truthfulness of such claims can be assessed by checking the payments to digital wallets that are assigned to the miner (Early, 2019). One company working on such solution is the US.-based blockchain company BanQu utilizes blockchain to establish economic identities and proof of record (which it calls “economic passports”) for unbanked persons (Stanley, 2017). BanQu has developed such solutions that can be used by farmers in India, Uganda and Zambia to track cassava and barley supplied to the subsidiaries of the multinational drink and brewing company Anheuser-Busch (Kshetri, 2021a). As of 2019, BanQu was working with telecommunications companies, battery and smart phone manufacturers, and jewelers to develop similar solutions for the mineral and mining industry. The company's plan is to launch the solutions for cobalt mines in the DRC, Zambia or Madagascar, and precious metal or gemstone mines in Botswana, Peru and Colombia. For instance, when firms in the cobalt SC add information to BanQu's blockchain, the miner will receive a SMS message, which confirms key data such as the quantity sold and the price. The SMS sent to the miner is also stored on the blockchain. This means that if a cobalt buyer has not paid the correct amount to the miner, the data would not match and the end-user of the mineral would know it. For the miner, the SMS record serves many purposes including a proof that they are a part of a legitimate SC (Early, 2019).

Some technological solutions are available but not being utilized up to their potential to address sustainability issues in M&M SCs. One such example is the Analytical Fingerprint (AFP), which can be employed to check the documented origin of 3 Ts and to ensure that smuggled minerals do not enter a SC. This technique involves comparing a sample from a shipment to reference samples stored in a database to test the claim regarding the documented origin. AFP relies on the identification of geochemical features, that is, distribution of chemical elements in mineral deposits from a given location (BGR, n.d.). Germany's Federal Institute for Geosciences and Natural Resources [Bundesanstalt für Geowissenschaften und Rohstoffe] (BGR) started developing an AFP method in 2006 (BGR, n.d.). The initiative was launched in response to calls by the UN for a scheme to verify the origin of conflict minerals mined in the DRC and neighboring countries. The BGR's recommendation is to apply AFP as an optional forensic tool to perform audits or risk assessments in the uppermost section of a mineral SC. Specifically, the BGR has suggested to perform AFP after extracting minerals from the mine sites and before homogenizing, that is, mixing the minerals in order to reduce the variance of the product supplied, for loading in a container for export. AFP can serve to verify the integrity, and credibility of other traceability schemes (BGR, n.d.).

5.2 Theoretical implications

The present study extended previous work related to governance in SCs (e.g. Boström *et al.*, 2015; LeBaron, 2021; Lèbre *et al.*, 2020; Macdonald, 2007; Vurro *et al.*, 2009) by focusing on various mechanisms by which blockchain can challenge the existing governance arrangements to mitigate various sustainability-related concerns facing the M&M industry SCs. First, and perhaps most important, blockchain promotes decentralized governance by creating and maintaining distributed ledgers of information (Allen *et al.*, 2019; Berg, 2017), which leads to reduction in the centrality and increase in the density of information flow. These mechanisms challenge the power of centralized entities such as a dominant SC entity (Abadi and Brunnermeier, 2018) and compel them to comply with sustainability standards.

This paper has also contributed to the research on sustainable SCs by examining how blockchain can address the current challenge related to determining the authenticity of sustainability-related information provided by various participants in SCs (Sønderskov and Daugbjerg, 2011). The integration of advanced technologies such as AI and satellite in blockchain systems makes it possible to apply the methodology of natural science, which is viewed as a better way of arriving at a truth (Knight, 1940). Such a methodology can help deal with second-party and third-party trust deficits and ensure relevant parties' compliance with sustainability standards.

A further contribution of the current work to research on SC governance is to examine blockchain's role in the context of standalone and discrete nature of modern SCs that have a low degree of integration with outside actors (Macdonald, 2007). This article demonstrated how blockchain-based system*s* connect outside actors in SCs, which can enhance the empowerment of marginalized groups. We also delved into a related mechanism to improve accountability. While prior research has emphasized the importance of disaggregating responsibilities between relevant decision-makers and coordinating decision-making processes to improve the well-being of less powerful actors (Macdonald, 2007), it is not clear how this can be achieved. With examples such as the shift of enforcement responsibility from the local government to the blockchain system in cobalt mining in the DRC, this article has promoted an understanding of the role of blockchain in facilitating such disaggregation and coordination in SCs.

The analysis of this paper also contributes to the SC governance literature by noting that SCs can be reconfigured with blockchain to help weak, peripheral and marginalized groups. Such groups' lack of voice and resources is found to be a key challenge facing today's SCs (Jiang, 2009; Macdonald, 2007). With examples such as ASMs' ability to enter the details of the materials in Circulor's system, the article showed how weak and peripheral actors can influence information flows, making it difficult to conceal unsustainable and irresponsible SC practices (van Tulder *et al.*, 2009).

5.3 Future research implications

In this section, we suggest some possible future research avenues. Weak and peripheral actors are forced to prove that their products are sustainable but the costs to participate in the non-blockchain traceability programs are prohibitively high. The ITRI Tin Supply Chain Initiative (ITSCI) was established in response to the Dodd-Frank Wall Street Reform and Consumer Protection Act, which requires US companies to vet their SCs. The ITSCI's "bagging and tagging" system is a widely used traceability scheme in the non-blockchain world. Depending on the type of mineral produced, miners in Rwanda pay between US$130 per ton and US$180 per ton to use ITSCI traceability system (Bizimungu, 2019). ASMs in Rwanda produce 0.5–3 tons/month (TPM) (Alliance for Responsible Mining, 2018). Taking the minimum level of production, an artisanal mining company producing 0.5 TPM (6 tons per year) is required to pay between US$780 and US$1,080 to use ITSCI traceability. At a 2019 mining forum in Kigali, the Chief Executive Officer of Rwanda Mines, Petroleum and Gas Board complained that traceability and due diligence costs were unfair (Bizimungu, 2019). Our preliminary analysis reveals that some blockchain solutions such as that of Circulor's system are changing the business models of ASMs by shifting traceability costs from miners to end users (Mwai, 2018). Future research is needed to provide more systematic comparison of blockchain and non-blockchain solutions in terms of costs and other indicators.

There is some anecdotal evidence that consumers prefer to buy products from companies that have adopted blockchain in their SCs (Kshetri, 2021a). However, there has been little research in this area, especially in the context of the M&M industry. Consumers with different demographic and socio-economic characteristics might have different levels of preferences and attitudes toward products traced using blockchain. In this regard, a second area of future research might be to examine the linkage between consumer characteristics and their responses toward products traced with blockchain.

Firms in a SC need to deal with various types of conflicts and violations. In the DRC mining industry, for instance, conflicts were found at three levels: company-government, company-local communities, and company-local employees (Mària and Devuyst, 2011). An intriguing avenue for future research is to analyze how different blockchain systems need to be designed to deal with different conflicts.

6. Concluding comments

Non-blockchain SC systems suffer from several drawbacks that can be overcome by using blockchains, which can drastically improve the ability of firms to identify, trace and track information about people, organizations and materials. Blockchain-based systems provide authentic and reliable information to select exchange partners more effectively. Such information help to design incentive structures for SC partners that comply with sustainability-related expectations. Compared to established traceability programs, blockchain solutions launched by some start-ups to trace minerals are more cost-effective.

A transaction that is confirmed and verified by the consensus of a majority does not necessarily signify a truth. In such cases, other major technologies such as aerial and satellite images, AFPs and AI could help reach closer to the truth. Especially the challenges of second party trust can be addressed by utilizing these technologies. Companies do not have to take their word for it when SC partners say that they engage in sustainable practices. The immutability feature makes it possible for interested participants to double-check the data in the ledger against the real-world condition to ensure that data are not misrepresented. Blockchain can thus make up for the lack of relevant institutions, the deficit in various types of trust or the problems associated with high transaction costs.

Blockchain facilitates decentralized information flow which reduces the prominence of powerful actors. In blockchain-based SC networks, actors along the value chain are more interconnected and there is an increased sharing of information, which would facilitate monitoring. Whereas non-blockchain SC networks are standalone, outside actors such as regulatory agencies are embedded in blockchain-based networks. Blockchain-based networks can increase the transparency of information, which can address issues related to disempowerment of marginalized communities.

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