Blockchain-based supply chain traceability in developing countries

Abstract
The purpose of this paper is to examine blockchain's roles in promoting supply chain traceability in developing countries. We illustrate such roles by focusing on the mineral and metal industry. It analyzes multiple case studies of blockchain projects in the mineral and metal industry. The article 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.

Keywords: artisanal and small-scale miners; blockchain; Dodd-Frank Wall Street Reform and Consumer Protection Act; environmental, social and governance; supply chain networks

1 Introduction

A number of serious environmental, social and governance (ESG) issues have been identified in supply chains (LeBaron, 2021). Such issues are especially pronounced in the mineral and metal industry supply chains (Lèbre et al., 2020). Mineral extraction activities' adverse impacts include environmental degradation, natural resources exploration, exploitation of child workers, human rights violations, population displacement and violent conflicts (UNSDSN, 2016). Like in other economic activities, most serious ESG risks reside deeper down in the supply chain (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 mineral and metal extraction activities including the use of child labor, human rights violation and environmental damages. This is especially true for cobalt. About 10-20% of lithium ion batteries consist of cobalt (Nelson, 2019). A battery of an electric car requires 10-20 kilograms of cobalt (Wolfson, 2019. Likewise, an average laptop battery uses about one ounce of cobalt (Jakobson, 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 include skin and respiratory toxicity they are potentially life-threatening (Taylor, 2020). The wages are as low as US$0.75/day. A large number of preventable deaths have been reported in the country's cobalt mining industry (Ledger Insights, 2020). Due to such issues, cobalt is also referred to as "blood cobalt" (LeVine, 2018) and is also known as the "Blood Diamond of Batteries" (Airhart, 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 U.S. companies to vet their supply chains. Countries that are covered under this legislation include South Sudan, Uganda, Rwanda, Burundi, Tanzania, Malawi, Zambia, Angola, Congo, Central African Republic, and the DRC (Ayogu & Lewis, 2011). Section 1502 of the Act requires mining companies to disclose if they source conflict minerals: tin, tungsten, tantalum and gold (3TG) – from DRC and nine neighboring 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). The new law is expected to come into force in the EU in 2021. From January 1, 2021, importers of tin, tantalum, tungsten and gold (3TG) in the EU will be required to carry out due diligence on their supply chains. That is, they need to check the sources of the minerals and metals they import and ensure that they were processed responsibly (European Commission, 2017).

Despite these regulatory developments, addressing ESG issues in the mineral and metal industry is not an easy task. The mineral and metal industry supply chains have unique, unusual and idiosyncratic characteristics. For instance, mineral and metals often change physical characteristics, chemical composition and other features along the supply chain. Commenting on the challenges involved in tracking tantalum, which is used for making capacitors for smartphones laptops and other devices, Circulor CEO and co-founder 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 doesn’t change into a diamond halfway through its journey to a consumer” (Hyperledger, 2019).

Blockchain, which is viewed as is a technological megatrend, has the potential to address many of the ESG issues in supply chains. Unsurprisingly some entities of governance such as the European Union (EU) have recommended that the use of technology such as blockchain be explored to enhance supply chain visibility in these countries (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 supply chain 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 & Varriale, 2020). Unsurprisingly the world's biggest companies from a wide range of industries such as automobile, lithium ion battery and diamond manufacturing have implemented blockchain to track their supply chains. Despite the importance of understanding blockchain’s roles in promoting sustainability in mineral and metal supply chains, in little research have scholars examined this issue.

Researchers have also emphasized the importance of studying the roles of technological innovations in supply chain management. Bush et al. (2015) have suggested scholars and practitioners to critically look at sustainability issues in global supply chains 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 various challenges in the existing governance arrangements (Kshetri, 2021a). Such challenges include the standalone and discrete systems of supply chain governance with a low degree of integration with actors outside the supply chain (Macdonald, 2007), and the lack or ineffectiveness of watchdog organizations to make sure that companies follow sustainability standards (Dietrich & Auld, 2015). There are also complaints that most of the existing governance arrangements have failed to close the geographical, informational, communicative, compliance and power gaps (Boström et al. 2015). These gaps have enabled the dominant groups to maintain their operation and authority, and stop innovations (Miller & 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 supply chain institutions, which is currently lacking (Macdonald, 2007; Kshetri, 2021a, b).

Finally, prior researchers have noted that while multinational corporations' (MNCs) corporate social responsibility (CSR) activities in developing countries have attracted increasing research attention in recent years, Africa has been relatively underrepresented in this research area compared to other regions. Moreover, existing studies dealing with this topic about Africa have mainly focused on two biggest economies in the region: South Africa and Nigeria (Kolk & Lenfant, 2010). This is arguably due to the fact that these two economies represent most of the foreign direct investment (FDI) patterns and, thus, the presence of MNCs in Africa (Kolk & Lenfant, 2010).

Mineral and metal 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 to track their CSR activities and performance. These MNCs' adoption of blockchain to track CSR are shaped by diverse motivations and circumstances. Kshetri (2021b) called for further research to better understand these diverse CSR issues affecting developing countries and least developed countries (LDCs) in Africa in the context of blockchain**.**

In light of the above, in this article, we address two related research questions: RQ1) What mechanisms exist for blockchain systems to mitigate various sustainability-related concerns facing the mineral and metal industry supply chains? 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 mineral and metal supply chains in developing countries. This article contributes to the literature on socio-environmental sustainability in supply chain by explicating how blockchain's key features such as decentralization, immutability, and transparency can ensure firms' compliance with sustainability standards in mineral and metal supply chains 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 mineral and metal 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 supply chain 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 & Heide, 2004).

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

Information, communications, and knowledge gaps

Boström et al. (2015) have identified various gaps that hinder a sustainable and responsible supply chain governance. The needs related to reliable, comprehensive, authentic, and credible information about sustainability impacts at various phases of supply chains are not fulfilled. These gaps are referred to as information and knowledge gaps (Boström et al., 2015*)*. In supply chain 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 from developing countries. 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). A problem with this statement is that 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 can increase profits by providing false information about their products (Sønderskov & 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 (Boström et al., 2015*)*. There is also a lack of collaboration and coordination among participants in supply chains. This leads to communication gaps *(*Boström et al., 2015*)*.

Implementation challenges

Fourth, standards that have been formulated and various sustainability principles and criteria that have been defined are not necessarily closely followed by supply chain participants. Ensuring supply chain 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 various stakeholders’ sustainability practices (Kshetri, 2020).

Power and accountability issues

An unequal distribution of power or the lack of power symmetry among various supply chain actors hinders the development of responsible and sustainable governance in supply chains. 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 & Regan 2001). For instance, some workers are forced to work in low-wage informal sectors.

Misleading persuasive practices

*S*everal supply chain governance arrangements have been operating despite the lack of evidence that these arrangements have contributed to sustainability improvements (Miller & Bush, 2014). 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 gap*s*. Such gaps can be attributed to the creation of an illusion of improvement without being accompanied by real improvement (Egels-Zandén & Lindholm, 2015) and low degree of transparency (Mol, 2015).

Lack of connection with actors outside supply chains

Current supply chains 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 supply chain governance that lack the wider components to connect actors outside supply chain institutions (Macdonald, 2007). Due to a low degree of integration with actors outside a supply chain, such supply chain governance systems thus have limited ability to improve the wellbeing workers and producers (Macdonald, 2007). There is the lack or ineffectiveness of watchdog organizations to make sure that companies follow sustainability standards (Dietrich & Auld, 2015).

Such problems become even more complicated when 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 in a position to increase control over key resources and opportunities. They also lack the ability to influence external decision makers to fulfill their responsibility (Macdonald, 2007).

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 in globalized supply chains? 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 supply chains 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 supply chain 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 supply chain characteristics: centrality and density. Centrality in a supply chain 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 in the network (Rowley, 1997). Supply chain density provides a measure of how actors along the value chain are interconnected. In a high-density supply chain network with high number of connections among nodes, an actor will receive more attention from other participants. The increased sharing of information among participants in the value chain would lead to increased monitoring of organizations (Neville & Menguc, 2006). Organizations thus face pressures to comply with stakeholder expectations.

In Vurro et al.'s (2009) typology of sustainable supply chain governance (SSCG) models, Acquiescent SSCG is of special interest for this study. This is because this approach corresponds to low centrality and high supply chain density and hence is compatible with the characteristics of blockchain. A high network density facilitates information flow and forces organizations to comply with sustainability standards in order to remain in the network (Frenkel & 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 to them (Jiang, 2009). In the absence of such supports, weak and peripheral actors will not be in a position to 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 supply chain institutions are needed to improve the wellbeing of the disadvantaged workers and producers (Macdonald, 2007). Theoretically the problem of disempowerment can be addressed by reconfiguring responsibilities across a plurality of decision makers within and beyond supply chains. 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 the co-ordination among relevant actors (Macdonald, 2007).

There have been some encouraging developments with regard to the roles of actors beyond supply chains in influencing ESG issues in supply chains. In the past few decades, various social groups have responded to what they view as a “distorted and unjust” governance system in global production and trading systems (Macdonald, 2007). Global supply chains 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, & Varriale, 2020; Kshetri, 2021b). More broadly, blockchain can help achieve various supply chain goals including sustainability (Di Vaio, & Varriale, 2020; Gurtu & Johny, 2019; Kshetri, 2018). Blockchain can make it possible to make sustainability-related indicators transparent, quantifiable and more meaningful (Gurtu & Johny, 2019; Kshetri, 2018). Prior research has noted in combination with other technologies, blockchain can help firms achieve the so-called triple bottom line (TBL) goals (Treiblmaier, 2019). For instance, researchers have demonstrated that by combining blockchain with the IoT and big data, firms can monitor and evaluate supply chains’ social sustainability performance (Venkatesh et al., 2020).

Blockchain’s features such as decentralization and immutability make it an ideal tool to improve supply chain traceability and address various shortcomings of traditional supply chains (Kim & 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 supply chain information systems can uniquely identify products they perform poorly in traceability. Traditional supply chain information systems *suffer from data silos*-- some supply chain *data* are accessible by some participants but are *isolated* from others. In order to be able to trace ingredients across multiple tiers of a supply chain, data must be shared in a tamper-proof way and must be accessible to relevant parties (Westerkamp, Victor & Küpper, 2020).

Improving the governance structures in supply chains is another key mechanism by which blockchain affect sustainability. This technology can provide visibility and provenance f and facilitate the automation of tasks such as payments, and settlements (Narayanaswami et al., 2019). For instance, b*lockchain can be used to create a* supply chain *map showing the flow of transactions and information, which* can help identify the weakest links and understand the degree and nature of risks and threats involved (Min, 2019). All these can lead to a reduction in opportunistic behavior (Schmidt & Wagner, 2019) and, consequently address unethical behaviors of middlemen and other actors (Treiblmaier, 2019).

Blockchain can render some intermediary tasks redundant (Tönnissen & Teuteberg, 2020). Such disintermediation can transform supply chains by making it possible to conduct transactions without relying on a third party's trust (Gurtu & Johny, 2019; Queiroz et al., 2019). Distributed trust based on the consensus of a network of participants can replace trust produced by third parties (Francisco & Swanson, 2018), which can help reduce transaction costs and facilitate market-oriented practices (Cole et al., 2019; Schmidt & 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 supply chain transparency and enhances consumers' perception of a firm's sustainability practices (Banerjee, 2018; Hald & 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, ultimatum game experiments have shown that in order to punish unfair practices, individuals are willing to give up some monetary benefits (Camerer & 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 supply chain sustainability by facilitating product traceability, improving the governance structures in supply chains, helping increase the authenticity of product information and replacing some intermediary tasks. However, no blockchain study focusing on sustainability has yet looked directly at mineral and metal industry supply chains. Valuable insights can be gained by considering how these mechanisms apply in the mineral and metal industry supply chains, which are more complex than supply chains of most other industries.

3 Methods

Yin (1989) argues that 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. Likewise, Stuart et al. (2002) has suggested that a case method is ‘‘appropriate and essential where either theory does not yet exist or is unlikely to apply, . . . where theory exists but the environmental context is different . . . or where cause and effect are in doubt or involve time lags’’. This study satisfies these criteria since blockchain deployment in supply chains 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 metal and mineral industry to build theory (Eisenhardt & Graebner, 2007; Kshetri, 2016). 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 deployment in mineral and metal industries in the past few years. Note that archival data is among a variety of recognized data sources for case studies (Eisenhardt & Graebner, 2007).

Following Eisenhardt (1989), we selected four 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) or dependent variable (Y) of interest are selected (Seawright & Gerring, 2008). One of the independent variables is characteristics of supply chains.

The cases we selected are extreme in the sense that they are among the earliest blockchain adopters in mineral and metal supply chains. In particular, prior researchers have suggested that best practices models are good candidates for case research (Eisenhardt, 1989).

We started with the biggest companies in the supply chains of the mineral and metal industry. The world's biggest diamond manufacturing and trading company is Russia’s Alrosa, followed by South Africa’s De Beers Group. Both have adopted blockchain in order to increase consumers' confidence that they purchased conflict-free diamonds. For instance, in December 2019, Alrosa teamed up with blockchain platform Everledger and to launch a diamond-focused retail mini-program with multi-purpose messaging, social media and mobile payment platform WeChat owned by the Chinese multinational technology conglomerate Tencent (alrosa.ru, 2019). Note that WeChat Mini Program provides advanced features such as e-commerce, task management and coupons to users. Diamonds from Alrosa sold in the WeChat Mini Program would enable full traceability from mine to consumer

The diamond traceability platform Tracr was developed by De Beers Group (debeersgroup.com, 2019).). Alrosa also uses Tracr (Sabine, 2019).

Among the minerals, cobalt has attracted the most regulatory and media scrutiny. We thus focused on cobalt supply chains. On a global basis, the leading use of cobalt is in rechargeable battery electrodes (usgs.gov, 2020). We thus looked at the status of blockchain adoption among the key players in the lithium ion battery industry and the automobile industry. In the lithium-ion battery industry, the two biggest companies in 2019 were China's Contemporary Amperex Technology Co. Limited (CATL) and South Korea's LG Chem (Bohlsen, 2019). 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. The traceability-as-a-service (TaaS) provider Circulor operates a blockchain platform across CATL's supply chain (Rolander, 2019).

The top four automotive companies by revenue in 2019 were Volkswagen, Toyota, Daimler AG, (also referred to as Mercedes-Benz), and Ford (Buldumac, nd). Of these, Volkswagen, and Ford are RSBN members. Other RSBN members include IBM, Huayou Cobalt, RCS Global, Fiat Chrysler and British-Swiss commodities trading company Glencore (Ledger Insights, 2019).

Volvo is a participant in CATL's supply chain that Circulor operates. In the future, Volvo plans to apply RSBN to other minerals found in batteries such as nickel and lithium (rcsglobal.com, 2019).

Daimler has also teamed up with Circulor to explore blockchain's potential to promote sustainability with a primary focus on environmental sustainability. A pilot project was conducted that involved the use of blockchain to track CO_2 emissions in cobalt supply chains of its battery cell manufacturers. It also tracks Secondary Materials, which are materials that are used, recycled and sold for use in manufacturing. The goal is also to document whether Daimler's sustainability standards are passed on throughout the supply chain. A blockchain-based system records the production flow of the materials and CO_2 emissions. It also records the amount of recycled material in the supply chain. The network also displays working conditions, environmental protection, safety, business ethics, compliance and human rights. The company's goal it to evaluate whether these indicators meet Daimler's sustainability requirements. Daimler will ask its direct suppliers to comply with the relevant standards. Upstream value chains are also expected to comply (Nastu, 2020). Pressures can be passed down to upstream value chains.

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 the mineral and metal industry supply chains. 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).

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

Degree of custom-made elements (the vertical axis)

Some of the blockchain platforms have been initiated by trading partners belonging to the same supply chain or by individual companies. They have deployed custom-built platforms for specific purposes. RSBN has diverse entities in a lithium-ion battery supply chain such as a cobalt manufacturer, a lithium ion battery manufacturer and several automobile companies. De Beers has also launched a GemFair program to log diamonds produced by small-scale African miners.

In other cases, platforms already developed by blockchain companies have been used. They are generic platforms that are used in a range of different supply chain applications. Another relevant dimension of diversity is that we have analyzed cases involving private as well as public blockchains, which allowed us to examine how different blockchains vary in terms of their roles in achieving sustainable and responsible supply chain governance. For instance, De Beers' Tracr uses Ethereum, which is a public blockchain. The remaining three cases make use of private blockchains.

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 supply chain entities)	RSBN [1]	De Beers [2]
Low (provided by a technology company)	Circulor [3]	Everledger [4]

Industry (the horizontal axis)

Different materials in supply chains pose different levels of difficulties in implementing blockchain to ensure tamper-proof tracking of production and distribution processes. For instance, it is relatively simple to track diamonds compared with ores such as cobalt and columbite-tantalum (coltan). Each individual 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 that rely on smelting and refining process technology are more difficult to track. The refining process increases the risk of clean batches of materials being mixed with other batches of products potentially containing conflict minerals (Uwiringiyimana & Lewis, 2018). The complexity also increases as the number of players in a supply chain increases. The global cobalt supply chains can be as deep as nine (Sauer & Seuring 2019) to 13 layers (Del Castillo, 2017).

Table 2 provides a brief description of the selected cases.

Table 2: A brief description of the selected cases

Case	Blockchain used	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 Ttraceability-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

3.1 Sources and characteristics of data

Gottschalk (1969) suggested that the sources of evidence as well as the evidence need to be evaluated. Some main criteria suggested for this purpose include a) time elapsed between events and reporting, b) openness to corrections, c) range of knowledge and expertise of the person reporting the events, and d) corroboration from multiple sources. Regarding the last point, data and information were triangulated from multiple sources.

We assessed data's internal consistency. As suggested by prior researchers (e.g., Kshetri, 2021b), we evaluated different data items for the same point in time. For instance, to compare the relative maturity of blockchain platforms to trace cobalt and diamond, we compared Everledger and Circulor at the end of 2017. Everledger's digital ledge had encrypted over 1.8 million diamonds by then (Williams, 2017) whereas Circulor had just been founded (Crunchbase. n.d.).

Additionally, the same data items have been analyzed for different points in time. For instance, Everledger's blockchain journey in tracing the provenance of diamonds, we found that the number of diamonds was 0 in April 2015 (when the company was just founded), 1.8 million plus in December 2017 and 2.2 million plus in April 2019 .

The reputation and trustworthiness of the source as well as content of data are important. In order to achieve these goals, 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 are important. In order to ensure the appropriateness of the age of the data, we followed the latest news items related to the cases chosen. In addition, we also visited the websites of the relevant companies developing, providing and utilizing the blockchain platforms discussed in this article for up-to-date data and information.

3.2 Brief discussion of the selected cases

De Beers' solutions

De Beers' blockchain solutions track diamonds as they move from the mine to cutter and polisher, and then to jewelers. The blockchain platform Tracr was launched in early 2018 to establish provenance, authenticity and traceability in diamond supply chains (Sabine, 2019). The platform was developed with Boston Consulting Group's Digital Ventures using the Ethereum blockchain. As of early 2020, more than 30 participants including Signet Jewelers, which owns Kay, Zales and Jared, Chow Tai Fook Jewelry Group and diamond mining company Alrosa had started using Tracr (Sabine, 2019). Tens of thousands of precious stones are registered every month on the Tracr platform (Debter et al., 2020).

Tracr started with tracking bigger diamonds. The initial test was conducted with 100 large diamonds. In mid-2018, the platform was used to track a rough stone of 2 carat and above (Bates, 2018). The plan was to track diamonds up to 1 carat in rough by the end 2019 and up to a half-carat in rough by the first half of 2020 (Bates, 2019). In the early test, most of its supply chain activities were owned or controlled by De Beers, which made compliance relatively easy to achieve (Hill, 2018).

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). Tracr assigns each diamond a unique ID. It uses scientific data involving 200 different characteristics such as weight, color, clarity, and photos to uniquely identify each diamond (Bates, 2018).

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

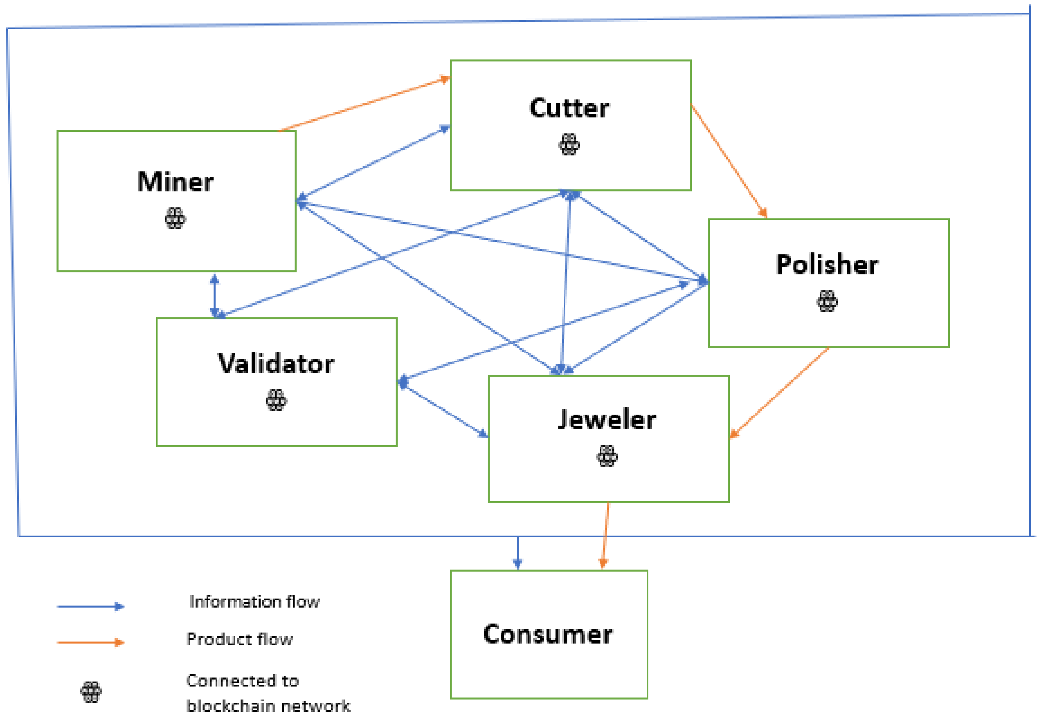
(Jamasmie, 2019). The goal is to make sure that diamonds originated in conflict zones do not enter the supply chain.

ASMs are required to identify and manage key risks defined in “OECD Due Diligence Guidance for Responsible Supply Chains from Conflict and High-Risk Areas” in order to participate in the GemFair program (Gemfair 2019). Among the major requirements is that ASMs need to identify the worst forms of child labor and address them. Compliance with the requirements is ensured through first party (e.g., a member completes a self-assessment workbook provided by GemFair), second-party (GemFair’s monitoring of mine sites bi-annually) and third-party (commissioning a third-party assessment of a sample of mine sites twice a year) verifications.

Tracr identified three major challenges that must be addressed for tracking diamonds in supply chains: 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 supply chain journey (https://www.tracr.com/)

Each organization involved in the traceability can use a smartphone or other devices to sign into a blockchain platform (Figure 1)**.** De Beers’ program records GPS locations for each diamond found. The diamond is then placed in a tamper-proof bag, which is QR-coded (Belton, 2019). GemFair provides a tablet for a participating mine site to log in the GemFair app. The app can function offline. However, the tablet must be connected to the Internet for production records to be stored in the GemFair system. After this step, the raw diamonds move on to the supply chain's next stage (Hill, 2018).

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



Everledger

The London-based technology enterprise Everledger's blockchain-based solutions are used to verify provenance of products. It was first used for tracking rough-cut diamonds. The system can be considered to be a digital expression of the Kimberley Process Certification Scheme (KPCS) (Clancy, 2017). Note that the KPCS is an initiative jointly undertaken by governments, industry and civil society to eliminate the flow of diamonds mined within conflict zones such as Sierra Leone that are used by rebel movements to finance wars against legitimate governments (Kimberly Process, 2016) and to support conflicts (UNCTAD, 2017).

Everledger uses IBM's TrustChain platform built on the Hyperledger Fabric (Jamasmie, 2019), 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 the need of a central authority.

Everledger gives unique cryptographic ID to each piece of diamond. It does so by storing diamonds' unique identities that are derived from more than 40 attributes. They include the so-called 4Cs—carat, cut, clarity, and color—as well as information about provenance and price. The cognitive analytics systems utilize AI to cross-check data related to regulations, relevant records, supply chain, and IoT to ensure that the gems from conflict regions do not enter the global supply chain (Thibodeaux, 2018). All permissioned parties in the supply chain have access to data.

As of April 2019, the company recorded the origins of about 2.2 million diamonds on its blockchain (Ricadela, 2019) as a part of its operations tracking high-value assets on a global digital ledger (Sabine, 2019).

As noted above, one of the necessary conditions for empowering marginalized groups would be to give them a voice and represent in decision- making processes (Macdonald, 2007). In this regard**,** Everledger and Swiss-based jewelry retailer Gübelin provide a no-cost solution to track colored gems produced or manufactured by ASMs. ASMs can use Everledger's blockchain platform to create traceability and document retention for free (Cholteeva, 2019). Being part of the blockchain network would allow them to exercise some control over the institutional transformation processes (Macdonald, 2007)**.**

Everledger launched its Diamond Time-Lapse Protocol in 2017, which provides real-time data related to origin, cutting and polishing, artisans' work and certification. The protocol has two user interfaces: Manufacturer & Retailer User Interface and Consumer User Interface. The Manufacturer & Retailer User Interface allows manufacturers to capture data as a piece of diamond moves through the manufacturing processes. Retailers can record relevant retail information, when the diamond reaches point of sale. The Consumer User Interface is a mobile application for iOS and Android operating systems. Customers can log in the system to view the complete provenance report of their purchased diamonds (IDEX, 2018).

The Responsible Sourcing Blockchain Network (RSBN)

The RSBN is an industry collaboration that aims to support sustainable and responsible sourcing and production practices. RSBN members include IBM, Ford, Volkswagen, Huayou Cobalt, Fiat Chrysler, Volvo, LG Chem and British-Swiss commodities trading company Glencore (Ledger Insights, 2019). The RSBN blockchain platform is built on Hyperledger Fabric and is overseen by responsible-sourcing group RCS Global (rcsglobal.com, 2019).

The project has been implemented in southern Congo (Ross & Lewis, 2019). At the point, where cobalt is bagged and tagged, the miner (Huayou) adds data into the blockchain. For successive stages and key events such as smelting and refining, data related to inputs and corresponding outputs are added to the blockchain. New pieces of information related to shipping and other details are added from partners along the supply chain 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 supply chains that they are designed as standalone and discrete systems that fail to connect actors outside supply chain 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 in the supply chain was traced through mines in the DRC which was refined in China (Khatri, 2019). The refined mineral was then sent to LG Chem's cathode and battery plant in South Korea, and then to a U.S.-based Ford plant (MENA Report**,** 2019). The three-continent journey of the cobalt refinement process took over five months (Nelson, 2019). In the future, RSBN users aim to expand to other metals. For instance, Volvo plans to apply RSBN to other minerals found in batteries such as nickel and lithium (rcsglobal.com, 2019).

Circulor

Circulor utilizes the Oracle's blockchain platform (OBP). The OBP is based on Linux foundation's Hyperledger Fabric as the foundational technology. Oracle is a BaaS provider. OBP sets up, manages, and maintains the blockchain platform for enterprises (Acharya, 2019). 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 supply chain participants' actions comply with globally recognized supply chain guidelines (Wolfson, 2019).

The application's field test was carried out for Tantalum mined in Rwanda and then for Cobalt used in Volvo Cars' electric vehicle batteries (Hall, 2019). For the project in Rwanda, 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). In 2014, Rwanda accounted for 50% of the production of global tantalum concentrates (Sanderson, 2015).

As of November 2019, Volvo, CATL and other supply chain participants were reported to record about 28 million material scans and other production events per month on the Oracle platform (Wolfson, 2019).

The combination of AI and blockchain can be an effective way to address *i*nformation and knowledge gaps, which represent a major challenge that supply chains are facing (Boström et al., 2015). There is the lack of reliable, authentic, and credible information about sustainability impacts at various phases of supply chains. Reliability and authenticity of data in the first mile of the supply chain, 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 whose role is to tag bags collude with smugglers and enter incorrect data (Cant, 2019). In Circulor's system, miners enter the data, whose identities are confirmed with facial recognition software (Ross & Lewis, 2019).

4 Findings and propositions

The cases discussed above illustrate the roles of blockchain systems in identifying, tracing and tracking relevant information in mineral and metal supply chains. 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 supply chain.

Blockchain systems to trace metals such as diamond are simpler to use 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. Everledger also has a longer experience in providing traceability solutions. Everledger was established in 2015 and started tracing the provenance of diamonds using a permissioned blockchain the same year (Allison, 2020b). Circulor was founded in October 2017 (https://www.crunchbase.com/organization/circulor). Everledger's solution is thus more mature compared to Circulor's.

In each of the cases analyzed above, major technologies other than blockchain are an integral part of the traceability systems. 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 supply chain journey in De Beers' system and Everledger's use of AI to cross-check data related to regulations, relevant records, supply chain, and IoT to ensure that the gems from conflict regions do not enter the supply chain (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 supply chain participants' actions comply with globally recognized supply chain 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 supply chain 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 & Graebner, 2007). To this end, Table 3 provides a theory summary. The table explains how the framework developed can be applied to understand the roles of blockchain in monitoring and enforcing sustainability standards in the mineral and metal industry.

Table 4: Patternmatching theory and data

Examples [Case No.]

Reduce centrality and increase density, which increase supply chain participants' compliance with sustainability standards (P_1)	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 supply chain partners' sustainability efforts (P_2) *Enhance the third-party trust and enforcement, to increase the compliance with sustainability standards.* (P_3)	De Beers[2]: records GPS locations for each diamond found. 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 (P_4)	RCS Global is the data validator of RSBN [1] Everledger [4] has included Underwriter Labs (UL) 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 supply chains, resulting in increased power for marginalized groups (P_5)	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 (P_6)	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).

4.2 A decentralized network with a high supply chain density

A supply chain system can be viewed as trusted relationships that are maintained with various "ledgers" (Berg et al., 2018; Casey et al., 2018). In the non-blockchain world, these ledgers and records tend to be maintained by centralized entities such as a dominant supply chain entity (Abadi. & 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 by enabling decentralized governance of such records (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 supply chain models are characterized by low centrality and high supply chain density and thus closely resemble the Acquiescent category in Vurro et al.'s (2009) typology of sustainable supply chain governance (SSCG) models. Due to a high degree of information flow and a low relative dominance of a given actor, it will be in the interest of supply chain participants to comply with sustainability standards. The tendency of manufacturers and retailers to exploit the information asymmetry to increase profits by providing false information about their products (Sønderskov & Daugbjerg, 2011) can be addressed with the deployment of blockchain. The above leads to the following:

P_1: Supply chain networks that use decentralized blockchains can reduce centrality and increase density, which increase supply chain participants' compliance with sustainability standards.

4.3 Impacts on trust and enforcement

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

More broadly, 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 factors such as 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 not an exaggeration to say that 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 enforcement measures by the state, have been relatively ineffective in the developing world. This increases the relative importance of other types of trust and enforcement.

Regarding process-based trust, which is related to the second party 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 & Lewis, 2019). The artisanal extraction of cobalt in the DRC has also been linked to toxic harm to vulnerable local communities (Nkulu et al., 2018). There is thus the lack of process-based trust due to the lack of some actors' engagement in trustworthy relationships.

The above problem is the result of the lack of the second-party trust, which is the trust placed in the entity that a party is transacting with (https://medium.com/hubtoken/hub-frequently-asked-questions-e6f4896310b8). 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 supply chains to track minerals are viewed as having attributes that are linked with trustworthy behavior. The challenges related to the deficits and the second and the third-party trust can potentially be addressed by incorporating blockchain in supply chains.

There are, however, some limitations of blockchain's applicability. An observation that needs to be carefully considered here is that while blockchain systems are secure, their data – like other databases – are only as accurate as what is entered. For instance, fraudsters try to counterfeit certifications of organic processes or farm inspections (Sustainable Food News, 2018). As noted above the lack of trust and lack of trustworthy behavior can be a problem with upstream firms in the mineral and metal industry.

While firms need to select potential supply chain partners with the ability and willingness to engage in sustainability practices, it is not easy to determine the authenticity of information provided by them (Sønderskov & 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 to track minerals and metals. 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 as to the location of mineral 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] to monitor mines in Rwanda, smartphones with GPS capability are used to pinpoint exactly the location where the ore was tagged (Ross & 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 supply chain 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 supply chain 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 (Thompson, 2020). Compared to solutions provided by a third party technology company [e.g., 3 and 4] or developed by a consortium [1], private blockchain platform's trust producing roles are likely to be more problematic when such platforms are developed and controlled by a private company [2].

A key mechanism to manage supply chain relationship and governance is to design incentive structures (Williamson, 1983) to reward desirable behaviors and penalize noncompliance (Wathne & 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 minerals that have been sourced unethically (Lewis, 2019).

Such systems have been or are being undertaken to track people and organizations as well. For instance, when a registered mining company that has a concession applies to use Circulor's [3] mine-to-manufacturer traceability of Tantalum, the coordinates the mine's operations and its historical production are entered in the system. Satellite data is used to verify that the mine is working (Burbidge, 2019). Circulor's plan is to use machine learning models and aerial imagery to ensure that child labor has not been used in the production process (Kapilkov, 2020). Based on above discussion, the following propositions are presented:

P_2: Blockchain systems are likely to enhance the second party trust and enforcement in supply chain partners' sustainability efforts.

P_3: 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 the existing governance arrangements in modern supply chains is their standalone and discrete nature with a low degree of integration with actors outside the supply chain (Macdonald, 2007). Blockchain-based system is superior in the sense that outside actors are connected in the supply chain systems. For instance, TrustChain, which is used by Everledger [4] has included Underwriter Labs (UL), as an independent third-party verifier. The idea is to increase the confidence of the TrustChain platform (Hill, 2018). The fact that information in the ledger is verified by third-party verifiers such as UL further strengthens the authenticity of information. Likewise, Everledger's [4] Diamond Time-Lapse Protocol allows customers to view the complete provenance report of their purchased diamonds (IDEX, 2018). In the same vein, RCS Global is the validator of the RSBN [1] (Todd, 2019). 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 & Lewis, 2019). The addition of such nodes leads to further increase in supply chain density and supply chain participants' propensity to comply with sustainability standards. The preceding discussion can be summarized as:

P_4: Compared to non-blockchain networks, blockchain-based supply chain networks are more likely to include outside actors, which can enhance the empowerment of marginalized groups.

Blockchain can fulfill the necessary conditions for sustainable supply chain management 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 supply chain 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 announced an investment in Circulor [3] (Volvo Cars, 2020). Three other investors SYSTEMIQ, Total Carbon Neutrality Ventures and Plug & Play also joined Volvo Cars Tech Fund in that round (Kapilkov, 2020a). Circulor plans to use funds from new funding sources to train and improve its machine learning models so that they can distinguish between children and adults with a high level of accuracy. With such a capability, the firm hopes to be able to use aerial imagery to determine whether a mining company has employed children in its operations (Kapilkov, 2020b). In this way, the enforcement responsibility shifts from the local government to the blockchain system. Blockchain and other major technologies can help redesign the responsibilities of various actors so that it will be possible to more effectively address the challenges of disempowerment. It is proposed:

P_5: Blockchain technology can reconfigure supply chains, resulting in increased power for marginalized groups

4.5 Measures for giving voice to marginalized groups

In traditional supply chains, 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. For instance, in Circulor's [3] system, the details of the material are entered by ASMs by registering on the system (Bennett, 2019). In Circulor's mine-to-manufacturer traceability solution for Tantalum, the enterprise 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 supply chain 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 for small companies and are easy to use

(Bennett, 2019) whereas *c*ompanies further up the supply chain need to pay and use more complicated interfaces.

The process begins with facial recognition. Once the miners open the app, there are three buttons on the front page. A step by step process is presented by clicking “Start”. Using Circulor’s system small mining companies do not see an increase in their workload. They may not know they are using blockchain. The final step of that registration is that the regulators approve it. Likewise, GemFair provides a tablet for a participating mine site to log in the GemFair app (Hill, 2018).

In this way, ASMs 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 can influence information flows, which would make it difficult to conceal unsustainable and irresponsible practices (van Tulder et al., 2009). The most important of all 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

P_6: Blockchain-based supply chain networks can give more representation to and increases the power of marginalized groups.

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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 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 Schem*e* (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 from the country. One estimate suggested put the proportion of illegal diamonds in Sierra Leone at least 50% (Maconachie and Binns, 2007). In March 2020, the UN General Assembly emphasized the importance of strengthening the KPCS in order to make it more effective and to ensure its relevance in the future. Likewise, complaints regarding lack of affordability and opacity of non-blockchain solutions used in tracing conflict mineral supply chains have been pointed out by regulators and other actors (Bizimungu, 2019). Blockchain-based solutions seek to alleviate some of these drawbacks.

Sauer & Seuring (2019) noted that most of the sustainability issues need to be addressed in the upstream supply chain and the non-blockchain technologies used in the current multi-tier sustainable supply chain management practices in mineral supply chains cannot ensure visibility and power to address these issues. This paper has provided insights into how blockchain's key features such as decentralization, immutability, and transparency can address some of the key challenges noted by Sauer & Seuring (2019) 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, which lack measures to address trust deficit. For instance, in order to ensure that child labor has not been used in the production process, GemFair program relies on first-party, second-party and third-party verifications. 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, analyse 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 in response to unique needs in mineral and metal industries. 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 has have been planned for the diamond industry.

Among major drawbacks of most blockchain networks is their inability to link a physical product to what is recorded on the ledger. A challenge that is involved in such networks is that while there is no central intermediary in a blockchain network and the network of participating users relies on a set of predefined rules and agree 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 (BangBit Technologies, 2018). 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 supply chain can try to reach as close to the real truth as possible.

Benefits of using blockchain to demonstrate sustainable practices also accrue to firms in supply chains. In order to signal the quality of standards and gain legitimacy from various stakeholders, firms need to make effects and results towards the stakeholders more transparent (Mueller et al., 2008). Blockchain based solutions discussed in this paper increase access to reliable information, which increases transparency.

The theory presented in this paper provides an approach to answering our two research questions posed earlier. They were: RQ1) What mechanisms exist for blockchain systems to mitigate various sustainability-related concerns facing the mineral and metal industry supply chains? RQ2) How can blockchain-based solutions promote socio- economic empowerment among disadvantaged groups working in this industry? Regarding the RQ1, the above discussion provides some insights into various characteristics of blockchain that promote sustainability.

As noted above, a blockchain-based supply chain network is characterized by a high network density, which facilitates information flow (Frenkel and Scott, 2005; Roberts, 2003). Such characteristics are especially useful in developing countries. 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 is making it increasingly difficult for companies to hide unsustainable practices in opaque supply chains. For instance, some firms use evidence based on narrow criteria of sustainability to justify their practices that are unsustainable, which favor powerful stakeholders and disregard the concerns of marginal groups (Bush et al., 2015). For instance, the world's largest cobalt-mining company Glencore reported that in 2019, it spent US$90 million on community development programs (2018: US$95 million (Environmental, Social and Governance data, 2019).), which was 0.04% of its 2019 revenue of US$215.1 billion (statista.com, 2019). It performs poorly on most other ESG issues. In its Environmental, Social and Governance data 2019, Glencore reported that seventeen people were killed in its operations in 2019, compared to thirteen during 2018 (glencore.com, 2020). Blockchain-based solutions make it difficult to hide poor working conditions and exploitation of workers. Machine learning algorithms can analyze aerial and satellite images of mine sites and flag hazardous working conditions. It is thus possible to know ESG violations before they occur rather than after the fact.

As to the RQ2, it is clear from the last two propositions that 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 the responsibility has been fulfilled by a party. Blockchain-led transparency can force companies such as Glencore to be more accountable. If companies know that their activities are being observed, they are likely to follow sustainability principles and meet the criteria that have been defined. 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 Ulrich, 2021), marginalized groups are being excluded from key decision makings. This article described the various mechanisms that play a role in empowering marginalized groups and improving their welfare. Blockchain-based business models are ensuring disadvantaged groups' access to critically needed resources and competencies to influence information flows. It is unreasonable to expect that blockchain solutions can be sent into rural Africa for artisanal miners to use them (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, which are central to the empowerment of marginalized groups. Supply chain participants alone, however, can do very 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 supply chain participants and key outside actors such as regulators and other third-party players.

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 U.S.-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 supply chain 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 global supply chain (Early, 2019).

Some technological solutions are available but not being utilized up to their potential to address sustainability issues in mineral and metal supply chains. One such example is the Analytical Fingerprint (AFP), which can be employed to check the documented origin of tin, tungsten, and tantalum (3T) ore minerals and to ensure that smuggled minerals do not enter a supply chain. This technique involves comparing a sample from a shipment to reference samples stored in a database to test the claim regarding the documented origin of the mineral. AFP relies on the identification of geochemical features, that is, distribution of chemical elements in mineral deposits from a given location. In this way, AFP can evaluate the plausibility of claim regarding the origin stated in the documents of a shipment (BGR, n.d.). Germany's central geoscientific authority that provides advice to the Federal Government in geo-relevant issues Federal Institute for Geosciences and Natural Resources [Bundesanstalt für Geowissenschaften und Rohstoffe] (BGR) started developing an analytical fingerprinting (AFP) method since 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 supply chain. 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 as a way to verify the integrity, and credibility of other traceability schemes (BGR, n.d.).

Tantalum and Niobium (Ta-Nb), which belong to *so* called transition metals due to their positions in the periodic table of elements, are almost always found paired together. These two metals are difficult to separate due to their shared physical and chemical properties. Specifically columbite ore which is rich in niobium and tantalite ore, which is rich in tantalum form a solid solution series known as the Columbite-Tantalite series (*Minerals.net*, n.d. a). When intermediary minerals exist between two end-member minerals[1] that are isomorphous (Minerals.net, n.d. b) (that is, the same crystal form because of identical molecular arrangement in spite of their different specific elements) a solid solution series is formed (Cengage, 2020).

Ta-Nb ores are extremely complex in terms of mineralogical and chemical composition. This is because columbitetantalite solid solution series found in different parts of the world vary widely (Melcher et al., 2009). Moreover, columbitetantalite solid solution series incorporates many additional elements. The wide variations in Ta-Nb minerals and ores also provides opportunities to develop mineralogical-geochemical-geochronological-based fingerprinting schemes in order to determine their origins. It was reported that as of 2008, over 350 samples of

[1] In an isomorphous (solid-solution) series, an endmember is one of the simple compounds (Definition of end member. *Mindat.org*; https://www.mindat.org/glossary/end_member

individual crystals and ore concentrates had been analyzed by BGR. More than 60% of them were from central and southern Africa (Melcher et al., 2009).

Melcher et al.'s (2009) used an electron microprobe (EMP), which is an analytical tool used to determine chemical compositions of small volumes of solid materials in a non-destructive way, to study minerals. The team found different mineralogical and geochemical fingerprints of minerals depending on the origin of a concentrate. For instance, bismutotantalite was found only in samples from Mozambique. Wodginite was frequently found in samples from Rwanda. Tapiolite was detected in concentrates from the DRC and Rwanda (Melcher et al., 2009). By utilizing AFP for minerals in the first mile of the supply chain, reliability and authenticity of information provided by the sellers of cobalt regarding the mineral's origin can be assessed.

5.2 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 U.S. companies to vet their supply chains. 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 are estimated to produce 0.5–3 tons per month (TPM) (Alliance for Responsible Mining, 2018). Taking the minimum level of production, an artisanal mining company producing 0.5 ton per month (6 tons per year) is required to pay between US$780 to US$1080 per ton to use ITSCI traceability. These charges are prohibitively expensive for subsistence miners such as ASMs. At a 2019 mining forum in Kigali, the Chief Executive Officer of Rwanda Mines, Petroleum and Gas Board (RMB) demanded that “the cost of traceability and due diligence must be reduced to make it affordable and fair” (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 mineral and metal 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 attitudinal and behavioral responses towards products such as diamond jewelry that have been traced using blockchain networks.

Firms in a supply chain need to deal with various types of conflicts and violations. In the Democratic Republic of Congo 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 supply chain systems suffer from a number of drawbacks that can be overcome by using blockchain systems, 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 is also helpful to design incentive structures for supply chain partners that comply with sustainability-related expectations. *C*ompared to established traceability programs such as ITSCI's: "bagging and tagging" system, 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 their supply chain 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 make sure that data in the ledger are not misrepresented. In this way, blockchain can 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 a supply chain. Blockchain is thus characterized by a low degree of centrality. In blockchain-based supply chain networks, actors along the value chain are more interconnected and there is an increased sharing of information, which increases monitoring of organizations. Whereas non-blockchain supply chain networks are standalone and discrete, outside actors such as regulatory agencies are embedded in blockchain-based supply chain networks. Blockchain-based supply chain networks can increase the transparency of information, which can address issues related to disempowerment of marginalized communities by allowing their participation in the network.

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