Political Geography 87 (2021) 102381

Contents lists available at ScienceDirect

Political Geography

journal homepage: http://www.elsevier.com/locate/polgeo

Digital extraction: Blockchain traceability in mineral supply chains

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ARTICLE INFO

Keywords:
Blockchain
Traceability
Mining
Digital extraction
Certification
Digital technology
Political ecology

ABSTRACT

Digital data — including technologically-mediated data generated by blockchain-enabled traceability — is performing an increasingly integral role in extractive operations, but scarce attention has been paid to the structuring effect of these digital technologies or the socio-economic spatiality of data-driven mining operations. Drawing on extensive qualitative research (interviews, participant observation, and two sets of survey data among actors relevant to these mineral supply chains), this article advances the notion of "digital extraction" to describe the collection, analysis, and instrumentalization of digital data generated under the banner of blockchain-based due diligence, chain of custody certifications, and various transparency mechanisms, situated alongside and in support of mineral extraction. The article mobilizes concepts from political geography and political ecology to argue that digital technologies of traceability in extractive processes potentially create new forms of control and exclusion or exacerbate existing social, political, and territorial dispossession through asymmetric relations of power and knowledge in mineral supply chains. Despite industry efforts to make mineral supply chains more sustainable by resorting to digital certification and traceability, the strategic uses of uncertainty, ignorance, and ambiguity undergirding blockchain-enabled traceability systems fail to challenge existing inequalities in resource use and access or fulfill the promise of transparency and accountability.

1. Introduction

Over the past two decades, global extractive networks have undergone significant reconfigurations due to the rerouting of supply chains to East Asia, the evolution of the commodities super cycle, and the diminishing availability of high-grade ore veins (Arboleda, 2020; Coy et al., 2017; Bridge, 2009; Narins, 2017). These transformations are nestled within two seemingly contradictory movements: first, the expansion of new "resource frontiers" and the undelivered promises of neo-extractivist policies and resource nationalism, especially in South America (Revette, 2017; Kohl & Farthing, 2012), and second, a more general shift away from what Dunlap and Jakobsen (2020) call conventional extraction toward "green" extraction. This reflects what Seagle (2012: 448) describes as an emergent "new political economy of mineral extraction" based on principles of sustainability, conservation, and transparency. Theoretically, these developments have been accompanied by a more encompassing definition of extractivism in critical geography and political theory, both spatially and by including processes of financialization or the extraction of value more broadly (Arboleda, 2020; Gago & Mezzadra, 2017). There has also been a renewed focus on materiality, heralding from resource geography, anthropology, and cognate disciplines, suggesting a more relational and distributed understanding of natural resources and the de-centering of human and non-human agency in natural resource extraction (Bakker & Bridge, 2006; Richardson & Weszkalnys, 2014).

A relative blind spot in this literature deals with the relationship between extractivism and digitalization. Despite an emergent focus on digital geographies (Ash et al., 2018) and a growing interest in new modalities of mining, from data (Mezzadra & Neilson, 2019) to crypto-currencies (Maurer et al., 2013; Calvão, 2019), the adoption of digital technologies by the extractive industry has not warranted the same attention. Across extractive sites, digitally-enabled instruments now monitor and control mining operations, autonomously collecting data and developing fully automatic transportation and excavation processes (Dadhich et al., 2016; Ellem, 2015). Since the mid-2010s, the mining industry also began rolling out digital-based certification technologies across mineral supply chains, adding to a plethora of regulatory instruments and governance initiatives meant to introduce accountability to an industry tarnished by human rights violations, child labor, and minerals used to fund conflicts (Bebbington et al., 2018). Paramount

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https://doi.org/10.1016/j.polgeo.2021.102381
Received 19 December 2019; Received in revised form 3 March 2021; Accepted 6 March 2021
Available online 24 March 2021

among these, blockchain technology entered the lexicon of the mining industry with the promise of surrendering the need for intermediaries or trusted partners to verify, audit or certify supply chain information. As an advanced version of distributed ledger technologies, blockchains effectively expand the scope and socio-economic impact of existing traceability initiatives.[1]

Balancing the expansion of new mining frontiers with a commitment to traceability and ethical business practices, digital data performs an increasingly integral role in the extraction and circulation of minerals across sectors, from fine jewelry to electronics. This article examines recent efforts to introduce blockchain-enabled alternatives to paper-based certification, which promise to facilitate more accurate and foolproof monitoring and end-to-end traceability in mineral supply chains. Drawing on scholarship in political geography and political ecology that theorizes the spatialization of power, digital materialities, and the emergence of socio-ecological conflicts, we argue that digital technologies of traceability are not neutral instruments for governing natural resource extraction. Rather, the extraction and utilization of digital records on geological features and mining sources holds the potential to actively reshape socio-spatial scales and create new digital territorialities with impacts on livelihoods, control and intermediation, and social inclusion.

Figure 1. Digital monitoring and app-based data collection in a cobalt mine in the Democratic Republic of Congo

We develop the concept of "digital extraction" to refer to these advances in the collection, instrumentalization, and analysis of digital data, and to assess the modalities of digital data creation, management, and ownership for upstream and downstream mining actors. Digital extraction attunes us to the way digital technologies are deployed to extract value in global supply chains, often under the guise of sustainability, ethical trade, or transparency. The article takes stock of how processes of digital extraction not only parallel but are increasingly inextricable from the material extraction of minerals, developed under the banner of blockchain-based due diligence practices, chain of custody certifications, and various transparency mechanisms. The concept of digital extraction reflects growing concerns with the extractive and exploitative nature of datafication, moving toward an understanding of what Sadowski (2019: 4) conceptualizes as "data capital" to emphasize the way data mediate "the relationship between real capital and commodities in the digital economy." In so doing, the article responds to Mirjam de Bruijn's recent description of the "political ecology of digital communication" as a "research direction we urgently need to develop" (2019: 34). More than a new form of digital legibility, the empirical focus of this article rests upon the "locked connections" between the physical and the digital – to follow Jannice Käll's (2018:134) remarks on blockchain control – as these are manifest in attempts to monitor, track, and certify the source and pathway of resources through complex supply chains of minerals and metals. Although this article centers primarily on mineral value chains, the notion of digital extraction could shed light on the complex extractivist dynamics of other value chains as well, namely agricultural commodities and forest products.

In the decade since the inception of blockchain technology, the mining industry has been at the forefront of embracing the potential of an open, decentralized, and distributed digital ledger, from the OECD's Blockchain Policy Forum (2018), the Responsible Minerals Initiative blockchain guidelines (2018, 2020), or other state and industry initiatives examined in this article to tackle the problem of the so-called "conflict minerals." This concerted effort has meant the possibility of creating a digital database where a tamper-proof, immutable record of transactions, ownership, and origin can be registered, time-stamped, safely stored, and securely operated.

This article does not seek to examine the technical precepts of the technology underpinning digital cryptocurrencies or contribute to the extant and vibrant literature on blockchains *per se*.[2] Instead, following Robert Herian (2018:130), we are more interested in the "'blockchain ecosystem', the politics it tries to hide, and the legal and regulatory ramifications it inaugurates." Though often-draped in technical language, it may be helpful to describe blockchain technology as a peer-to-peer digital protocol. As a digital ledger designed to avoid double transactions, blockchain is commonly presented as decentralized (spread across multiple locations), transparent (with public transactions), open (unrestricted access to use or operate) and secure (through cryptographic operations and a consensus-based algorithm). These foundational principles have largely become a moot point in light of disparate and heterogeneous blockchains, governance models, consensus protocols, and their overall architecture. Despite the prominence of the *public* model of the Bitcoin blockchain, ran through a proof-of-work protocol (defined in the majority control of computational power), *private* blockchains are now more commonplace. These blockchains, usually created by private organizations and corporations,

[1] By traceability, we refer to both industry initiatives meant to trace and track the properties of minerals to render knowledge about their origin, source, and other identifiable properties available to the end consumer. As we suggest in this article, the process of data disclosure, recording, and due diligence associated with traceability programs is at once a technical and political process with socio-economic consequences.

[2] The interdisciplinary literature on blockchain technology has become a thriving field of research, too vast to be aptly referenced here. For introductory studies to blockchain, see Narayanan et al., (2016); Tapscott & Tapscott, (2016). For an overview of blockchain for humanitarian objectives, see Zwitter and Boisse-Despiaux×2018; Cartier et al. (2018) offer a helpful introduction to traceability and tracking opportunities in the gem industry, including blockchain-based platforms.

operate as permission-based centralized ledgers, where access is restricted and privileges inhere in one's "stake" (from early investors to currency holders, and thus naming its proof-of-stake protocol). In both instances, centralization and mediation have come to largely replace the original aspirations of blockchain technology (Swartz, 2017, p. 92). Despite the illusion that blockchains can operate openly, anonymously, and independently of intermediaries, as Çalışkan put it (2020:553), "blockchains do not disintermediate, but reintermediate." In this article, we examine how blockchain-based traceability initiatives in the mining industry have come to foster new forms of control, exclusion, and intermediation, be it by governance design, unequal access, or inequity of resources needed to operate them.

Despite its early adoption by the mining industry, the use of blockchains is not unique to minerals or metals, and pilot projects making use of some variation of blockchain technology have multiplied to solve the perennial problem of record-keeping in financial and commodity transactions. The creation of forms of digital identity, also known as "self-sovereign," and the use of blockchain-enabled applications for humanitarian purposes, have become two of the most promising but equally problematic arenas for the use of this technology (Kshetri & Voas, 2018; Zwitter & Boisse-Despiaux, 2018). These initiatives open a series of ethical issues and technical challenges of political and social relevance, namely the lack of permission by the targeted users, the collection of biometric data on vulnerable populations, and identity management through private-run, unsecured digital ledgers. Digital extraction associated with blockchain-based digital certification and traceability in the mining industry creates similar problems in trying to come up with a solution for technology-based enforcement of due diligence mechanisms. Moreover, blockchain-enabled traceability initiatives harness the discursive power of sustainable development to perform consumer-centered (rather than producer-centered) models of sustainability and corporate social responsibility that reinforce existing logics of value extraction. These attempts to make the "'material world' visible and legible to those (industrial consumers) whose decisions help shape it," Gavin Bridge suggests, can "be used … to question – rather than affirm – existing patterns of resource use" (2009: 1238).

The first section of the article presents our methodological approach to data collection and analysis, followed by a conceptual and theoretical section. This discussion, drawing from scholarship in political geography and political ecology, situates the problem of knowledge, power, and dispossession as applicable to blockchain technology and the emergent digital-based certification processes. In the third section, we describe traceability initiatives in mineral supply chains, with a particular focus on the problem of control, oversight, and data validation in blockchain-enabled projects in the diamond sector. We follow this discussion with an analysis of digital extraction in the cobalt mining sector in the Democratic Republic of Congo, emphasizing the usage, effects, and potential limitations of digital data. The final section of this article examines the problem of sustainability and transparency of ethical certification in terms of what we designate as the ambiguous promise of blockchain technology. We conclude with a critical reflection on the sustainability of certification in the digital age.

2. Research methodology

Research for this article relied on a combination of different data collection strategies to mirror the complexity and wide range of actors and processes pertaining to digital extraction. To ensure that data remains rigorous, verifiable, and reliable, the researchers developed a set of initial questions related to technological developments in traceability and blockchain usage in mineral supply chains, which were in turn reformulated and refined during data collection stages. In the ethnographic approach at the core of this research, consideration was given to the ensemble of data generated through different techniques (literature review, interviews, participant observation, and surveys). Assembling this variety of primary and secondary data reflects the on-going and emergent processes of digital extraction to generate key insights on the future of blockchain-traceability of mineral resources.

Data were gathered between 2016 and 2020 in a variety of settings, including OECD's Responsible Mineral Supply Chains Forum (Paris), the Kimberley Process Certification Scheme (Antwerp), and mining sites in the Democratic Republic of Congo (Kolwezi), and discussed systematically by the authors to answer specific and granular questions pertaining to the relevant sites and actors. As part of the authors' broader research projects on transparency technologies in the mining industry and certification in global agricultural supply chains, a total of 90 interviews were conducted with actors in mining companies, multinational corporations and NGOs, certification bodies and laboratories, blockchain developers, and standards development organizations. In the subset of data analyzed in this article, our interviewees include blockchain developers and proponents, as well as other relevant stakeholders partaking in the development and implementation of traceability initiatives, including gemmologists and field agents responsible for data input. Interviewees were asked about the potential of blockchain technology, their hopes and techno-imaginaries surrounding these digital instruments, and the potential and limitations of digital technologies more broadly for supply chain management.[3]

Data were also drawn from two surveys: the first was conducted online in 2018 with digital miners ($n = 115$) involved in crypto-mining.[4] The second ($n = 81$) was held in September 2019 in Kolwezi, Democratic Republic of Congo, among cobalt miners. This data included information on miners' revenue, choice of mining site, and adaptation to newly introduced traceability and accountability mechanisms. A representative sample of blockchain-based traceability and due diligence initiatives in the mineral sector was methodically monitored and documented, including implementation area, potential integration in blockchain pilot projects, and targeted mineral.

3. Blockchains and the political geography of digital materials

State and corporate actors have begun promoting and certifying more transparent and ethical mining practices to mitigate the environmental and reputational risks associated with geological sourcing and extractive practices, from corporate social responsibility programs to the advent of new regulatory standards for mineral supply chains.[5] Many of these schemes imagine a future where social responsibility and environmental sustainability are digitally mediated, relying on the ambiguous promise of advanced digital technologies like blockchain certification. As a new immaterial resource undergirding existing extractive policies, digital data of origin and traceability calls for renewed attention to questions of access, knowledge, value, and forms of exclusion and dispossession (Thatcher et al., 2016). Scholarly research has been devoted to resource access, the mobility of resources, and their effects on livelihoods. However, the new representational economies of resource control associated with digital extraction require a new

[3] Interviews followed a semi-structured questionnaire and research participants were recruited based on a combination of purposive and snowball sampling across institutions and biographical positions with the aim of generating a representative sample spanning the trajectories and knowledge expertise. To cross-check information, relevant interview transcripts and other unstructured data (field notes and media content) were coded and analyzed using Atlas-ti.

[4] Participants were mainly based in North America, Europe, and Australia, and the survey assessed the costs of digital mining operations, available hardware and computational power, and the technological limitations of small-scale crypto-miners.

[5] Prominently among these, the International Council on Mining and Metals meeting on traceability in minerals and metals supply chains (2017), the Kimberley Process Certification Scheme (KPCS), Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Protection Act (2010), the OECD Due Diligence Guidance for Responsible Mineral Supply Chains (2011), or the European Union's impending Conflict Minerals Regulation (2021).

framework to assess who holds the right to produce, move, and control these digital data as well as the configurations whereby digital data potentially allow for the commodification and unequal appropriation of nature. We anchor this analysis in the material turn in resource geography and related disciplines to stress how digital extraction enables the emergence of governable spaces through digital materialities and non-human actors (Bridge, 2009; Watts, 2004) and to highlight the social, political, and infrastructural conditions allowing for the exercise of power in new digital territorialities.

Scholarly engagement with the cultural, social and biophysical value ascribed to natural resources has led to critically reassess the subject-object dichotomy in extractive processes. This effort to recompose nature-societal assemblages (McFarlane & Anderson, 2011) in provisional and oftentimes "precarious" (Bakker & Bridge, 2006, p. 17) connections of culture and nature, humans and non-humans, comes hand in hand with the reemergence of materiality in resource studies. Drawing from earlier approaches in Science and Technology Studies, Actor-Network-Theory, and anthropology (Latour, 2005; Appadurai, 1986; Law & Mol, 1995; Mintz, 1985), recent scholarship has dwelled on the social and material purview of non-human agencies to privilege a processual understanding of resource-making in distributed and assembled relations of materials, labor, knowledge, or violence (Richardson & Weszkalnys, 2014; Rolston, 2013; Simpson, 2019). This attention to how resources are known, transformed, and experienced, recalls resource geographer Erich Zimmermann's "pithy aphorism" in World Resources and Industries (1933) that "resources are not, they become" (cited in Bridge, 2009, p. 1220). Zimmermann's now famous dictum putting forth a relational and dynamic conceptualization of resources offers a particularly suggestive approach to processes of digital extraction and the digital materialities underpinning it. As Bridge (2009:1221) argues, Zimmerman "misses the inherently political, contested nature of the resource imaginary" and fails to explore "the tension between those who have a subsistence relationship to a resource, and those whose relationship is based on the logic of extraction or harvesting for exchange." Similarly, the digital expertise deployed in blockchain-based initiatives interacts with existing political-economic structures to construct resources' origins as techno-political facts. Importantly, and reminiscent of Simpson's (2019) argument about bitumen's "narration" as a resource, the discursive and material production of resources hinges on a particular narrative of extraction, be it transparent, ethical, or sustainable, and how it gets to be entangled with data, as we will show. In other words, digital extraction – conceptualized here as the digitalized, technologically-mediated production, storage, analysis and dissemination of data generated by tracking and tracing the physical origin and socio-ecological impacts of minerals and other natural resources – influences the becoming of resources as the sourcing is manifestly made an enduring and constitutive element in the process.

These ostensibly more technologically-advanced and more secure modes of governing natural resource extraction necessitate new forms of monitoring and surveillance, "thus facilitating forms of technocratic environmental governance that potentially alienate or marginalize non-expert stakeholders" (Cavanagh & Benjaminsen, 2017, p. 202). As Käll observes, it is precisely the "security" supposedly afforded by blockchain technology's strong encryption and cryptographic evidence that leads to "locked-up control over the digitalized worlds we inhabit" (2018: 134). This is to say that blockchain proponents' claims of openness, democratization, and accessibility should be nuanced, particularly as these technologies precipitate significant changes for workers, institutions, and societies at levels both structural and mundane. As we will see, the political life of digital materialities is particularly pertinent in light of corporate-led attempts to create hybrid or private blockchains. In these privately-operated blockchains, the maintenance of consensus – or the enforcement of governance and control mechanisms – is placed squarely in the hands of major banks and private companies or those holding a stake in it (e.g., pre-mined coins). This portends the removal of actors organized outside the purview of these institutions or that otherwise face obstacles to access "closed accounting blockckchains," to follow Çalışkan's actor-based taxonomy of public and private blockchains (2020). Political geography allows us to take stock of whether, and how, blockchain-based digital extraction generates new digital territorialities built upon processes of social and economic exclusion in mining economies, unequal data production and validation, or inequitable distribution of incentives needed for end-to-end traceability.

The immateriality and immediacy of digital extraction challenge existing approaches to the exercise of political power in territorial terms. Since at least the 1980s, the spatialization of resource-making has warranted considerable attention to examine the "spatial fix" (Harvey, 1981) of capitalist expansion in reproducing uneven development and inequality (Smith, 1984). If "resource-making activities are fundamentally matters of territorialization – the expression of social power in a geographical form" (Bridge, 2010, p. 825), then the emergence of new spaces of enclosure and enclave gained currency to account for the limited benefits of extractive economies to local communities and the persistence of unequal power relations between Global North and South (Appel, 2012; Calvão, 2011; Ferguson, 2006; Le Billon, 2003; Sidaway, 2007; Watts, 2004). The forms and effects of value capture associated with enclaved extractive economies would lead in turn to the reproduction of "useable" and "unusable" spaces (Ferguson, 2005, p. 380) or "governable or ungovernable spaces," each associated with its own forms of conflict and violence (Watts, 2004, pp. 53–54).

Finally, we suggest that technologies of data extraction and digitalization more broadly require attention to the properties and revolutionary potential of new data infrastructures (Kitchin, 2014), alongside the "political geography of materials … associated with the production of information," to follow Barry's (2013: 5) analysis of the disputes surrounding the construction of the Baku-Tbilisi-Ceyhan pipeline. If blockchains can be regarded as "infrastructures that enable the movement of data as representation and value" (Çalışkan, 2020:2), it is opportune to recall Murrey's (2015: 69) point on the relation between power concentration and legitimacy in her study of the Chad-Cameroon pipeline, in which the "uneven dispossessions effected by oil pipelines … are enacted through large-scale, complex bureaucratic structures." Though framed in bits and digital data, these suggestions resonate with Mitchell's (2002: 90) analysis of the effects of technological advances in colonial map-making, heralding a "new form of political power" characterized by "knowledge and command of space" (2002: 90), or Agrawal's (2005: 30) point on the effects of colonial technologies of governing forests brought forth by "representational innovations" in "measuring, aggregating, differentiating, and analyzing. Traceability initiatives relying on blockchain and other digital technologies, as we will see, reproduce this logic on a significantly more intrusive scale.

4. Political ecology of knowledge and power

As discussed above, political geography's conceptual frameworks help us explore the social and political dynamics producing marked social and territorial differences inherent in digital certification initiatives. A political ecology approach, in turn, reveals how these schemes may serve to consolidate the exercise of power and control with potentially detrimental impacts on the societies and environments they are ostensibly designed to improve. The field of political ecology has long been premised on the critical articulation of nature-society relations, and the politics of how these emergent traceability technologies are instrumentalized provides a fertile ground for advancing these debates. The point is to connect power relations and broader material relations to local realities, histories and practices, bringing forth the politics of entanglement and articulation linking environment and politics, where the latter is often understood as the way particular forms of knowledge correspond to the governance of the former (Peluso and Watts 2001). It is worthwhile recalling here Blaikie's (1985) theorization of the relationship between the power to categorize some things as problems and the power to control the resources mobilized as solutions against those problems. In the case of soil degradation, the assumptions that underlie different conservation approaches reflect the unequal power dynamics within the global development apparatus.[6] For Thompson, Warburton and Hatley (1987), there is a complex political economy around the relative credibility of knowledge about and proposed solutions to these problems. Controlling the narrative – being able to establish the facts – is key, not what the facts are *per se*, but rather, "what would you like the facts to be?" (Thompson & Warburton, 1985, pp. 115–135, p. 116).

As a stepping-stone toward narratives of sustainable and ethical resource extraction, the increasing reliance on digital technologies for the ethical certification of commodities ignores "the systemic features of capitalism that make the system inherently wasteful and unmanageable" (Hajer, 1995, cited in Foster et al., 2011:33), inasmuch as the exorbitant energy often required to power some modalities of blockchain technology. Indeed, under the guise of consumer awareness, the focus rests on technological fixes that are profitable for the companies and banks that develop and enforce these certification schemes. This allows the supporters of these technologies to make optimistic promises about their potential social and environmental impacts, discursively linking the financial performance of extractives companies to the social and environmental welfare of communities around sites of extraction. In tandem with this idea, De Bruijn (2019) proposes a political ecology of digitalization that shifts attention away from familiar narratives of the so-called "digital divide" between Africa and the rest of the world, to highlight instead the way efforts to digitalize Africa's communication technologies, including the data collection, storage, and dissemination technologies discussed in this paper, give rise to new assemblages of knowledge and power. As Cavanagh and Benjaminsen (2017: 202) observe, these "new epistemologies and discourses" have "led to a sweeping re(e)valuation and (re)production of both space and nature," especially to the extent that buzzwords like transparency, blockchain, and big data become increasingly ubiquitous.

Bringing together changing approaches to digital materiality and socio-spatial enclosure from political geography with political ecologists' recent concerns with questions of digital technologies (rooted in longer-standing concerns with power and knowledge in Western-led development initiatives) we have developed a conceptual vocabulary for understanding the way blockchain-enabled traceability schemes in mineral supply chains can be deployed as new resource management tools to facilitate the linkage between digital operations and physical materials. In fact, the political ecology of blockchain technology and digital certification in highly fragmented mineral supply chains should pay heed to the interconnections between regulated market economies and the local, often-neglected participation of mining actors. Taking digital traceability as a central analytic interface, these should be taken not as two polar ends of a global market but in their mutual constitution (see Guyer, 2004 for a similar point). Crucially, in analyzing the politics of digital traceability schemes, political geography and political ecology come to be two sides of the same coin: The former attunes us to the uneven spatiality of power, while the latter focuses our attention on the socioecological effects of that power and the politics surrounding its exertion.[7] With the development and enforcement of blockchain-enabled traceability systems, which require the constant collection and input of data from actors all along the supply chain, this authority is increasingly based on who has access to (and control over) not only the mineral supply chains, but the data supply chains, as well. In the following sections, we show how the adoption of digital technologies plays out in the mining industry's attempts to enhance mineral traceability, attentive to how data is extracted and commodified in diamond and cobalt mineral supply chains.

5. Blockchain traceability and the validation of data control

The number of traceability programs for gemstones and other minerals has proliferated over the last two decades, hand in hand with the exponential increase in the unwavering belief in their perfectibility. In the diamond sector, the most prominent certification program is the Kimberley Process Certification Scheme (KP). Despite its relative success in stemming the flow of conflict diamonds, KP state and corporate stakeholders are currently exploring the adoption of blockchain technology into its certification process given the risk of paper-based obsolescence, human error, and being superseded by high-tech start-ups.[8] The most high-profile of these start-up companies is London-based Everledger. If the world's diamond production is subject to KP's screening and certification processes, it may soon well end up in Everledger's global registry for diamonds, to make faith on the ambitious plans of this company. As one of the first companies to roll out blockchain technology to monitor this high-value commodity, soon followed by De Beers' own blockchain initiative, Tracr, Everledger offered a technological fix to the perennial problem of conflict diamonds, with at least two million diamonds catalogued thus far. Everledger's adoption of digital ledger technologies for diamond traceability, and the possibility of an immutable chain of documentation of provenance, has captured the imagination of industry actors and raises critical questions on the appropriation and instrumentalization of the knowledge acquired in the process of digitally extracting this information.

For Everledger's CEO, Leanne Kemp, the "transformation effort" of this blockchain technology is structured around the "digital enablement of the standards in place" – such as the KP – rather than seeking to replace them.[9] There are two complementary aspects to Everledger's initiative: first, the physical inscription on the diamond, be it on the girdle, star facet or crown, with a "subsurface marking with data matrix codes which stores the attributes of that diamond through the chain." According to Kemp, registering these attributes on diamonds above 0.25 carats (50 mg or 4 mm) is affordable and technically feasible. This inscription phase – also called digital incarnation, or thumbprinting – takes place at the moment of polishing. Therefore, it would not guarantee a 'chain of custody' capable of verifying authenticity and provenance throughout the entire supply chain. Despite perfunctory tests conducted in artisanal mining sites, Kemp is adamant that "at the

[6] Blaikie describes a 'colonial' model of soil conservation wherein locals are viewed as "lazy, ignorant, backward or irrational," which he contrasts against more contemporary 'formal' models of soil erosion and conservation, noting the persistence of colonial structures in both ideas and institutions.

[7] The specific interdisciplinary approach we take on here is not unprecedented. Through the dual lens of political geography and political ecology, For example, Le Billon (2001) focuses on conflicts that were driven by differential access to and control over scarce resources such as oil and diamonds to illuminate the unequal power relations between different groups of actors, whereby a key source of power in transnational mineral supply chains is the authority to make legitimate claims about what constitutes 'good' versus 'bad' governance, 'weak' and 'failed' versus 'strong' and 'successful' states, or 'responsible' and 'irresponsible' supply chain management strategies (Le Billon, 2001, pp. 577–579).

[8] According to the 2016 mid-term report (available online), blockchain-based solutions were proposed to "eradicate false KP certificates and reduce the impact of human error while uploading data."

[9] Interview, June 2018. Unless otherwise noted, subsequent citations are taken from this interview.

moment we're only looking at this from private organizations, only members of the industry." And yet, for an industry currently producing hundreds of millions of diamonds annually, individually marking and recording these stones poses unresolved logistical, technical and political issues. These issues cast a doubt on pilot projects designed to track minerals through the use of blockchain technology in that the solution to ensure digital certification would in turn open a new problem for millions across the world who rely on mining for their livelihoods. Moreover, by supplying data mid-way through its supply chain, the most risk-laden part of the supply chain, the so-called "first mile," remains opaque.

Attempting to tackle the issue of only tracing part of the supply chain, Daniel Nyfeler, Director of Swiss-based Gübelin Gem Lab, introduced a physical "paternity test" to bring "trust" and "confidence" to the consumer by tracing the "provenance of emeralds back to the exact mine."[10] In a presentation delivered to the 2018 KP Intersessional Meeting in Antwerp, the laboratory director stated that "the industry wants transparency, traceability, and they want audited, certified traceability. (…) Instead of just waiting, we started an initiative. We are developing technologies that make possible audited traceability." Rhetorically, Nyfeler asked, "How can we exactly determine the exact mine where it came from? The answer is let's do a paternity test." The process can be summarized as soaking each individual stone with DNA-based, nano-sized particles encoded with the mine's information, which would then permeate the stone's natural crevices with information about its origins. Rather than assuming that it is possible to determine a stone's origin by its geomorphological features – a near impossibility in pure, transparent stones that lack the internal inclusions that could give away its source – the lab proposes to physically introduce information about the mine, the mining company, and the extraction date onto the stone itself. Not unlike a microscopic barcode, this practically invisible, non-removable DNA-information would survive cutting, polishing, testing and mounting. The process of "bathing" the stones in nano-particles, Nyfeler explained, allows specific information "to penetrate the fissures, to adhere to the stone wall, so tightly that they can't be removed, but not affect the properties of the stone." Gübelin takes ownership of the entire process, which is admittedly impractical to small-scale mines: "We do not give the technology to the mining companies …. Either we do it ourselves or we commission it to an auditing company."[11]

The success of the original "paternity test" led Gübelin to introduce its own digital tracking "provenance-proof blockchain" in 2019, in partnership with Everledger, aimed primarily at colored gemstones and pearls. After one year of tests with "high-profile partners" including Toronto-listed Fura Gems, the blockchain project was presented publicly during the Tucson gem show in February 2019, promising an open and autonomous ledger where every transaction can be registered and safely stored. Although seeking to develop a low-tech solution with "artisanal miners" and other small-scale actors "in mind,"[12] the provenance-proof blockchain maintains some of the problems of its competitors. As a permission-based ledger this blockchain stands in opposition with the tenets of distributed accountability. Although arguably less energy-consuming, control over access and dissemination to data is centralized in these private blockchains; while aiming to be inclusive of non-industrial or corporate actors, the registration process and background check of participating users, the need for an online connection to upload data, and the lack of incentives for these actors raise questions on the actual purview of this initiative. Finally. the importance of "basic gemological tools," including access to scales and other measuring devices, may further imperil the participation of non-corporate actors, even as it promises to further interlock physical and digital data. Not to be outdone, the Swiss Foundation for the Research of Gemstones (SSEF), one of the leading certification laboratories in Europe, has also recently introduced its own traceability assessment to identify the authenticity, potential treatment, origin, and quality of gemstones through a mix of DNA testing, gemological techniques, and documentation strategies. As SSEF director Micheal Krzemnicki explained to an audience of curious participants of GemGenève, Geneva's principal gem and jewelry show, in May 2019, this information can be integrated in a blockchain whenever a gemstone is tested in a laboratory.

Well-intended as these initiatives may be, the hype and promise surrounding them seem to address in part the need to attract venture capital as well as the principles of sustainable and responsible supply chains. Despite the inclusiveness with which some are designed, they fail to foster "data agency" for a wider spectrum of actors, and preclude – in the name of transparency as an absolute creed – the possibility of rethinking existing configurations of value capture and distribution for small-scale actors. Fundamentally, the proposed blockchain solutions are geared toward digital experts or large-scale corporate institutions without considering ways of overcoming often-insurmountable political and technological hurdles, be it in terms of digital communication, access barriers, or control over digital platforms. There is already evidence of this in other modalities of mining as in the case of cryptocurrency miners, where the lack of a system of incentives capable of fostering mass collaboration have pushed small-scale miners away from the promises of blockchain rewards (Calvão, 2019).

This exclusion represents the biggest challenge for multi-stakeholder blockchain initiatives across the mineral supply chain and is compounded by the lack of democratic control over blockchain protocols. This lack of democratic control appears paradoxical because the positive association between blockchain technology, on one hand, and the traceability of commodities and the transparency of their production networks, on the other, is actually premised on a principle of radical decentralization. As a distributed ledger that is copied and stored on servers around the world, it invokes a sociotechnical imaginary of unmediated democracy. This imaginary holds despite the challenges mass digitalization poses to the democratic governance of – and access to – increasingly digitalized archives of knowledge and experience (see Thylstrup, 2019). Given that these digital ledgers are spatially distributed, multinational corporations, national governments, central banks, or other actors are theoretically not able to alter or control the information stored within them. However, not all blockchains are public, open, and decentralized, undermining their democratic and distributed potential. As mentioned earlier, most blockchain-based initiatives deployed by the mining industry retain the power of access firmly in the hands of for-profit corporate actors, or with undisclosed commercial interests over data control, unlike the public oversight of multi-stakeholder initiatives and regulatory standards (or the collaborative control of disintermediation effected in public blockchains). Moreover, the perceived lack of interoperability across private blockchains – i.e., the ability to use different blockchain protocols interchangeably at the user's discretion, also known as "blockchain agnosticism" – reinforces (rather than challenges) the undemocratic control over these digital ecosystems. As it was explained to us in May 2019 by Nathan Williams, author of the white paper "Protocol for Due Diligence in the Raw Material Supply Chain" and leading developer for Minespider, a blockchain protocol for responsible mineral sourcing in partnership with some of the world's leading tech and automobile companies, "interoperability is a major concern given the proliferation of protocols."[13]

Aside from the lack of democratic control and public oversight over private blockchains, the technical challenges of data validation, the

10 Unless otherwise noted, subsequent citations are taken from the June 2018 presentation to the Kimberley Process meeting.

11 The process has been outsourced to UL, who applies the technology for the companies as a neutral third party.

12 This citation and subsequent ones, unless otherwise noted, are taken from public documents available in provenanceproof.com.

13 Interview, May 2019.

insufficient system of incentives, the fragmented and incomplete records of the physical commodity, as well as the informational asymmetries among participants in the supply chain (Rakic et al., 2017), there remains another risk of sidelining small-scale miners in at least two different ways. First, as suggested above, blockchain-enabled solutions for traceability run the risk of mirroring forms of political-economic exclusion occurring with digital miners. In a survey of digital miners (who secure and register transactions in proof-of-work blockchains), the rising cost of computational power and energy as well as the involvement of capital-intensive players with more robust computing power led to the exclusion from the system of rewards in place of digital miners organized outside large industrial conglomerates.[14] The second risk can be framed as the rule of digital experts, to recall Mitchell's eponymous work. Moving beyond representations of space that remain relatively static, no matter how detailed or accurate, these new initiatives attempt to capture and integrate information about space, origin, and production in order to generate a dynamic map of transnational supply chains, however limited to upstream or downstream actors. And yet, the increasing reliance on blockchain technologies perpetuates a conventional understanding of natural resources as stable and homogeneous biophysical entities that can be singularly registered in a digital ledger, obscuring the way these are dynamically entangled with other configurations of socio-cultural and economic value.

Let us examine this problem more closely by way of a comparable example in anti-deforestation initiatives. In these initiatives, blockchain technology is increasingly seen as a way to solve the problem of verifying the carbon offsets that underlie payments for ecosystem services (PES) schemes such as the REDD + program. The ostensible benefits of so-called cryptocarbon are diminished by a number of pitfalls, however, and Howson et al. (2019) show how efforts to deploy blockchain to shore up these market-based conservation initiatives often end up worsening existing problems or generating new ones. Using tokenized cash transfers to address the unequal distribution of conservation benefits, for example, gave rise to situations in which rural people were more easily surveilled and controlled. At a more fundamental level, blockchain does not address the fact that a carbon accounting approach to sustainable development represents "a fetishized abstraction of 'nature' in both image and value" (id: 4).

Despite their disparate social and environmental goals, these initiatives all seek to collect information related to mining sites, companies responsible for cutting and polishing diamonds, price, or ownership history. Returning to the case of mineral supply chains, since the original push for accountability in the extractive industries inaugurated by the KP, similar techniques of origin traceability have been developed to enhance knowledge about mining sources. From Everledger's original registry for provenance and traceability of diamonds, currently in the process of expansion to other commodities, to Chow Tai Fook's collaborative blockchain with the Gemological Institute of America to record grading information, or Lucara-owned Clara Diamond Solutions, a blockchain-enabled project to ensure provenance and transparency in diamond sales, the mining industry seeks to "unlock" the potential of this technology without having addressed the underlying inequalities that blockchain would make transparent.

The updated Responsible Minerals Initiative Blockchain Guidelines (2020) sought to address these inconsistencies by espousing principles of decentralization, interoperability, respect for self-sovereign data, and consensus mechanisms capable of avoiding record tampering.[15] And yet, these guidelines fundamentally contradict the industry's extant blockchain initiatives, in which digital protocols are commonly centrally stored, privately-ran and permissioned self-standing platforms. Interestingly, even in the most advanced traceability initiatives, data are only collected down to the level of the mining site, neglecting to record information about labor conditions, environmental impact, or benefits accrued locally: without third-party assessment, once the tracked stone moves up the supply chain, its traces become disentangled from the extractive site and no longer recorded. These digital traceability solutions rest upon a principle of "asset" management, useful for those holding the "custody" of the commodity, but falling short of blockchain proponents' radical promise of the possibility of a different political economy of extraction and the socio-cultural embeddedness of these resources. Similar to the failure of blockchain-enabled systems for carbon accounting to address the abstraction of nature, the optimistic narratives around blockchain and traceability in mineral supply chains contribute to the fetishistic abstraction not only of "nature," but of "society" as well, reducing the socioecological relationships between the panoply of geographically dispersed producers, consumers, middlemen, non-human actors, and local environments to a constantly increasing stream of data stored on digital ledgers.

6. Cobalt in the DRC: powering new digital territorialities

To understand exactly what kinds of data are required by blockchain-enabled traceability initiatives, we now turn to the specific case of digital extraction in the cobalt supply chain: from whom, by whom, and for whom are these data collected, stored, analyzed, and disseminated? Our analysis of these planned and nascent digital certification schemes and the vast amounts of data on which they rely complicates the narrative of actors who promote the uptake of blockchain technology in sustainable supply chain management. We do so by highlighting the unequal distribution of both power and benefits emanating from these traceability and transparency schemes, particularly salient in cobalt mining in the Democratic Republic of Congo, to where we now turn.

The Democratic Republic of Congo (DRC) holds the world's largest known reserves of cobalt, with upwards of 70% of global production sourced from the provinces of Lualaba and Haut Katanga in Southern DRC. Along with so-called "digital" minerals (the "3Ts," tin, tungsten and tantalum), cobalt extraction has been in the spotlight for two related reasons: first, a number of revelations – ignited by the 2016 Amnesty International Report "This is what we die for" and further consolidated in December 2019 with a lawsuit filed against the use of child labor by US-based tech companies in cobalt mines – shed light on the exploitative conditions under which cobalt is sourced to power the electric power industry and electronic devices (Sovacool, 2019). Second, cobalt is extracted by both industrial and artisanal methods, with artisanal sourcing representing a significant component of current supplies (Al Barazi et al., 2017). As a symbol of future 'clean' development, cobalt holds the contradictory promise of powering the future of 'green' technologies while its extraction precipitates negative social and environmental effects. Similarly, blockchain initiatives heighten the gap between the technological aspiration of fully digitalized supply chain traceability information led by multinational companies and the labor conditions of small-scale miners and local, national companies, left largely outside the scope of these initiatives over political expediency, economic cost, or technological design.

In response to consumer pressure and international regulations, and

[14] This entailed a major shift away from a 'hobby' or odd job with collaborative purposes toward a competitive, commercially-driven techno-industry. The majority of users surveyed deployed last-generation graphic processing unit (GPU) powered machines, whereas only a smaller fraction (12.5%) used more advanced and costly application-specific integrated circuit (ASIC) hardware to register and validate transactions across the blockchain. For a comparable example, Rosales (2019) examines gold mining and crypto-mining operations in Venezuela in response to the withering of State functions. Unlike the context described here, the Venezuelan State eventually became fully implicated in this forms of "radical rentierism," to the point of creating its own crypto-currency.

[15] Responsible Business Alliance (2020). Responsible Minerals Initiative Blockchain Guidelines, second edition. Available online: responsiblemineralsinitiative.org.

to ensure regular supplies of cobalt, large-scale, international mining and trading companies have developed partnerships with local cooperatives and NGOs to formalize and coopt the artisanal mining sector. These have been publicly presented as a means to enhance due diligence and labor standards and to mitigate potential reputational damages from undisclosed cobalt sourcing.[16] Trafigura, one of the leading trading companies in the world, partnered in 2017 with Chemaf, a local DRC mining company, to launch the Mutoshi project in Kolwezi. Along with a local cooperative and PACT – a US-based NGO responsible for in-site monitoring – the project registered a peak of 5000 artisanal miners. Zhejiang-based Huayou Cobalt, with its local subsidiary Congo Dongfang Mining, developed in 2017 a similar project in its Kasulo and Kamilombe concessions, with upwards of 14,000 miners at its height.

In a 2019 visit to these cobalt mines in Kolwezi, we had a chance to learn more about these initiatives. Aside from these companies' reliance on a flexible workforce to avoid the risk of price fluctuations and exposure to standards' violations,[17] these hybrid artisanal-industrial projects – known locally as "model mines"– are built upon the premise of digitally monitoring commodity flows and compliance with rigorous traceability mechanisms, envisioning future possible integration in blockchain-designed solutions. As a strategic mineral sourced from conflict-prone regions, cobalt has warranted considerable attention by corporations and other stakeholders to conjure a blockchain-solution to certify cobalt "free" of conflict and child labor violations. Cobalt Blockchain Inc, based in Canada, has been engaged since 2018 in two joint venture supply agreements in the Kolwezi and Lubumbashi region. Despite these agreements and pending license approvals, the company seems to be more resolute in gathering capital through stock offering operations, with limited actual implementation in the DRC. Comparable initiatives developed by NGO IMPACT and Canada-based data analytics company Consensas in eastern Congo for conflict minerals and ethical gold mining rest on more inclusive principles by digitally monitoring the commodity and exploring the possibility of blockchain integration.[18] The Better Cobalt Sourcing Program – more recently renamed "Better Mining" – is operated by RCS Global Group and currently present in the DRC cobalt mines. Under a subscription service contracted by mining companies, it audits, verifies data, monitors mining sites, and offers digital traceability services. It has been a key partner in ensuring due diligence for mining companies engaging with the artisanal sector in the Kolwezi region. More recently, RCS has led the creation of the Responsible Sourcing Blockchain Network, a membership-based collaborative endeavor involving, among others, IBM, Ford, and since late 2019, Anglo-Swiss mining and trading multinational Glencore. The "network" builds upon Hyperledger Fabric and is poised to become commercially viable in 2020 by coupling corporate performance and consumer transparency.[19] Despite the multiplication of digital solutions and blockchain-ready initiatives in the cobalt sector, there are a number of limitations to these programs as seen from the grounded realities of cobalt mines in the DRC.

First, there is no political commitment to implementing a traceability system. As an agent working for a responsible sourcing initiative told us matter-of-factly, the provincial government of Lualaba "forbade" and is adamantly opposed to "transparency," perceived as an added cost to be borne by state authorities.[20] According to this agent, echoing a more widespread sentiment, coltan "is not a conflict mineral, so there's no need to do it." This much was confirmed to us by a provincial minister, who complained of the loss of competitive advantage brought by the costs of reporting and third party auditing. As these artisanal miners do not receive a wage and are paid by extracted ore according to prices established by mining companies, the costs of digital monitoring and certification are potentially displaced to the miners themselves. In this case, the digital transparency project of blockchains could be seen as being at odds with the objectives of economic development. Second, and in a different rendition of the now truistic formulation of "garbage in, garbage out" to describe redundant or useless information registered on blockchains, a monitoring agent explained to us that blockchain solutions do not solve "the problem": if "corruption at the basis remains" or until the information is "100% reliable" the problem of upstream traceability will remain. Instead, his suggestion was that traceability ought to be developed alongside "reasonable" due diligence, without fully surrendering the need for trusted partners to verify, audit or certify. Similarly, the risk of "contamination" – whereby cobalt-rich ore deposits from different sources could be mixed together – troubles the feasibility of these "model mines" and has recently led Huayou to suspend buying from artisanal sources (a decision partially motivated by COVID-19 and decreased cobalt prices). Third, and most critically, upstream traceability is regarded with skepticism by artisanal miners. In a survey conducted with artisanal miners operating in these "model mines," only 2 respondents (or 2.47%) claimed to trust existing instruments to measure the quantity and grade quality of cobalt ore. Extrapolating from the widespread unawareness (14% of respondents) regarding dedicated areas of artisanal mining (Zones d'Exploitation Artisanale) predicted in the DRC's mining code, it is not difficult to conjure a general suspicion with any attempt to digitally track and record cobalt transactions.

It may be insightful, therefore, to consider what kind of data are collected and how they are generated in DRC's cobalt mining sites. First, data collection is restricted to the areas highlighted earlier with organized and formalized artisanal mining, so as to avoid reputational damages perceived by unregulated mining. In these cases, corporate-run traceability programs accompany formalization efforts under the aegis of large-scale industrial mines. We have here an instantiation of digital extraction generating, and constituted by, a new form of spatial enclosure circumscribed by the limits assigned to the project. Second, as we were told, though framed as such for an international audience, the responsible sourcing initiative "doesn't officially do traceability" but "documentary traceability." This is to say, in the case of this initiative, that agents in each mine were responsible for conducting a "mining site assessment," including information on incidents, perceived violations, and census data on artisanal miners. This information is uploaded to an app, given a score according to standards defined by the organization, and reviewed by an external regional officer, who cleans it for inconsistencies, and finally screened by a country manager based outside DRC. Once the review process is concluded, the information is made available on a platform to which funding parties are given access. In these instances, and in contrast to the distributed and decentralized principles of blockchain accountability, the mediation of the human element is unavoidable. Moreover, it does not adequately perform traceability of extracted ore, and has limited purview to avoid having cobalt sourced elsewhere enter its supply chain.

Having established what kinds of data are collected and who is collecting them, we turn finally to the question of for whom these data are being collected, that is, the ends to which traceability tools like the DRC initiative, Everledger or provenance-proof blockchain are meant to respond. Although industry publications feature glossy images of

[16] Not to be mistaken with the recently launched (September 2019) "Cobalt for Development" initiative, gathering the German development agency (GIZ), BMW, Samsung and other companies with the purpose of improving artisanal working and living conditions.

[17] This corporate cooption of artisanal mining and "outsourcing of responsibility" is examined in Calvão et al., (2021).

[18] See https://www.consensas.com/impact-consensas-asm (last accessed October 1st, 2020).

[19] See RCS Global (2017). Blockchain for Traceability in Minerals and Metals Supply Chains: Opportunities and Challenges, Available online at rcsglobal.com, and https://www.rcsglobal.com/blockchain-traceability/(last accessed October 15, 2020).

[20] We choose not to disclose the name of the organization behind the initiative for confidentiality reasons.

artisanal miners and allude to abstract social and environmental benefits of improved traceability, the dominant narrative centers on responding to consumer demands for sustainability and optimizing supply chain management, at the price, even, of reorganizing existing corporate alliances and cooperative structures. Indeed, according to Sadowski (2019: 6), the optimization and management of systems – such as supply chains – through the collection and analysis of data are two key modes of deriving value from "data capital." A good case in point is Alrosa and De Beers' widely reported collaboration on the latter's blockchain solution, Tracr. What a political geography and ecology approach to digital certification in the mineral supply chain makes clear is that the emergence of new techniques and technologies of transparency and traceability primarily targets downstream actors – i.e. consumers – rather than challenge the existing paradigm of resource access, use, and management (Bridge, 2009, p. 1238). This potentially erases production sites or presents a "unidirectional" (Mantz, 2018, p. 34) account of commodity chains split between producers and consumers, thus failing to empower local communities to develop their own monitoring and transparency devices (id:47). Until then, the project of digital transparency and blockchain remains a fraught and ambiguous promise.

7. The value of BLOCKCHAIN'S ambiguous promise

When actors involved in the responsible and sustainable management of mineral supply chains discuss the benefits of implementing blockchain-enabled traceability systems, they maintain a large degree of ambiguity about the technology itself, relying on the inherent ambiguity of terms like "sustainability," "social responsibility," "transparency," and "traceability" to speak to diverse audiences who might not otherwise have come together around a particular cause. Eisenberg (1984) argued more than 35 years ago that organizations can use ambiguity strategically in order to achieve various goals. His definition of strategic ambiguity turned on an important claim not about ambiguity, but about clarity: "clarity is only a measure of communicative competence if the individual has as his or her goal to be clear" (Eisenberg, 1984: 230). One of the key functions of ambiguity that Eisenberg identifies is its role in promoting what he refers to as "unified diversity." Ambiguity, he argues, allows for the concomitant existence of different views by allowing people to agree about some abstract principle even while they interpret that principle in potentially very different ways. Notions of sustainability and transparency are similar, something that many actors in global supply chains embrace in an abstract sense but interpret and enact in very different ways.

Ambiguity is also a theme familiar to political ecologists, who have shown what ambiguously-defined targets and techniques of development interventions mean for the actors leading them (and profiting from them), and how these relatively powerful actors are rarely held accountable because of the plausible deniability this ambiguity affords them, even when those interventions fail on multiple fronts (Escobar, 1995). Closely related to ambiguity, uncertainty and ignorance can also be manufactured at multiple scales to the advantage of powerful actors like governments and corporations (Best, 2005; McGoey, 2012; Oreskes & Conway, 2010). Uncertainties, whether natural, manufactured, and/or capitalized, offer powerful actors the opportunity to "privilege certain forms of environmental knowledge over others" (Eren, 2017, p. 403) and, consequently, to enforce their own self-interested regimes of knowledge-making. As Eren (2017) explains, studying the "political ecology of uncertainty" reveals how the inability to predict and model natural processes such as stream dynamics in Turkey generates conflict between different groups with different forms of knowledge who compete for resources. Babidge (2019) makes a similar point in her analysis of a conflict between a lithium mining company operating in Chile and a community negatively impacted by the extraction of groundwater. By emphasizing the uncertainties and unknowns of groundwater dynamics, mining companies "sustain ignorance" as a way to "[maintain] the conditions for extractive activity" (Babidge, 2019, p. 90).

During an interview in Washington, DC, an impacts evaluation manager at a sustainability standards organization told us that traceability is undermined by standards and certification regimes that have insufficient anti-corruption measures.[21] Although rare, he contends, there is a chance that the data can be "fudged" or altered through a sustainable certification to facilitate producers' access to global markets. To combat this possibility would require better auditing and intrusive surveillance technologies (satellites and drones, for instance) combined with more democratic ways of storing and sharing the data collected, which, in this informant's opinion, blockchain-enabled traceability systems would provide. For all it seems, blockchain and panoptic surveillance are two sides of the traceability coin. The ambiguous promise of blockchain ultimately serves to justify increasingly invasive techniques and technologies of data collection, and reinforces the idea that a technological 'fix' exists for various social and ecological challenges. The ambiguity inherent in on-going digital extraction for blockchain certification is extrapolated toward new levels of dispossession and socio-spatial exclusion, even as blockchains or blockchain-ready initiatives aim to holistically capture the entirety of the supply chain.

The ambiguous promise of these blockchain-based traceability and sustainability projects suggests that the optimistic narrative about blockchain is valuable for companies not because it seeks to improve the way supply chains are managed, but because those promises are inherently ambiguous. In turn, this would allow lead firms like De Beers, Rio Tinto, and Dominion to justify increasingly invasive monitoring and surveillance programs with indefinite guarantees of improvement. The notion of digital extraction we have developed in this article helps emphasize the material effects of data-driven and technologically-mediated sustainability initiatives that are often analyzed in terms of their immateriality and etherealness. As Sadowski reminds us, data such as those upon which blockchain-based ethical sourcing certifications rely do not simply "[exist] out in the world as a distinct thing readily available to be harvested," but have to be forcibly extracted. Remaining attuned to this dynamic "emphasizes the people targeted by, and the exploitative nature of, dataveillance" (Sadowski, 2019, p. 6). The "will to improve" exhibited by ethical sourcing advocates has long been a rationale for social and economic development initiatives that reinforce the power of experts and elites (Li, 2007), but the promise of blockchain goes beyond this now well-documented form of governance by appearing to explicitly challenge the authority of otherwise powerful actors with revolutionary rhetoric (Crandall, 2019). In the fog of uncertainty surrounding developments in blockchain technology, what remains clear is the relatively unchallenged ability of corporate actors to find new ways to extract value.

8. Conclusion: sustainable certification in the digital age

As we have seen, digital technologies such as blockchain-enabled traceability systems seem to offer a technological fix to the classic Foucauldian problem of knowledge, power, and panoptic surveillance, especially pertinent in the context of digital certifications (Eden, 2011). On closer inspection, issues emerge relating to claims of expertise and access to the technology and infrastructures necessary to benefit from blockchain. Similar to the "policy reform dossiers" described by Blaikie and Muldavin (2015: 419), a distributed ledger is "not merely a repository of data sitting on a computer … but a process of creation, production and promotion" of knowledge oriented toward a certain goal, in this case rendering global supply chains transparent and the concomitant traceability of globally portable and mobile commodities. Proponents of blockchain initiatives, especially with regard to transparency and traceability in global production networks, assure consumers, investors, and regulators that this technology will promote

[21] Interview, April 2019.

efficiency, prevent fraud, and ensure that ethical certification processes are more effective and, crucially, more credible. And yet, this optimistic tone serves to hide the fact that the blockchain-enabled "fix," and the massive amounts of data they require to function like they are "supposed to," do little to question the extractive nature of capitalist accumulation or the relationship between powerful corporations and investors, on one hand, and increasingly disempowered local actors, on the other.

We have argued that the narrative of blockchains as open, democratic platforms that promote transparency in conflict-ridden global commodity chains diverges from the actual blockchain projects being developed by the mining industry to meet growing consumer demand for traceability. But even the narrative of blockchain's revolutionary potential often rests on ambiguous promises that exhibit not only a fundamental lack of what blockchain is and how it might be implemented in sustainable supply chain management, but also, and perhaps more importantly, a casual disregard for the political ramifications of blockchain's proliferation as a governance strategy in global value chains. In market-driven approaches to sustainable development such as corporate-led traceability approaches, blockchain quickly evolves from a buzzword to a "fuzzword," "[concealing] ideological differences" between different actors in global value chains (Cornwall, 2007). Proponents of blockchain-enabled traceability systems assert that it offers a tamper-proof, immutable record of transactions, ownership and sourcing and decreases the need for intermediaries, trusted partners and the likelihood of fraudulent behavior. Nevertheless, it comes with its risks that we should ponder: first, despite growing attention to the lack of interoperability across blockchains, these remain acute problems that may enhance private control over these digital ecosystems; second, the move from public oversight in multi-stakeholder certificates to permissioned controls in private blockchains. In other words, only the companies and private organizations participating in the blockchain are called upon to enforce internal consensus and rules. Irrespective of the warranted criticisms made against the Kimberley Process for the diamond industry, we should not fail to realize that these proposed solutions – and the notion of centralized or permissioned database locations – are at odds with the decentralized principles of distributed accountability and the "democratic" processes of securing consensus within the blockchain network, or the control over access and dissemination of information.

This speaks to a broader point on processes of sustainable and ethical certification: it has been demonstrated that processes of certification and the bureaucratic regimes that accompany them have tended to increase the divide between producers and consumers, replacing personal relationships by the mediation of paper technologies. In this regard, digital certification should serve to decolonize the digital divide between North and South. Rather than helping mitigate this divide, processes of digital extraction have failed to fulfill the promise of transparency and accountability or address asymmetric relations of power and knowledge in mineral supply chains. Moreover, relying on blockchain either in 'real life' or 'merely discursively' as the foundation of traceability initiatives delimits the kinds of data that can be recorded, stored, and presented as evidence for claims of traceability. Data that are not easily quantifiable – data that do not fit neatly into the cells of a spreadsheet – are marginalized, lost in the noise of ever expanding 'big data' sets, the generation and storage of which are now par for the course in supply chain management.

By obscuring relations of power and the divergent motivational forces pushing different actors in the supply chain to pursue traceability (or even to see traceability as desirable in the first place), the ambiguous promise of blockchain and its proliferation in market-driven sustainable development discourse defines problems of knowledge and ignorance that can only be solved using terms and tools developed and largely controlled by economic elites and technological experts. Related to that, blockchain-based approaches to traceability reinforce the primacy of certain types of data (that is, certain epistemological regimes) that align with the position of elites and that do not quite challenge or interrogate global disparities in power, namely alternative approaches that foreground sociality, trust, long-term relationships, or even anti-consumption or degrowth strategies that diminish the need for traceability by decreasing the amount of industrial inputs in the first place. Finally, the salient debate on the exorbitant consumption of energy required by blockchain technology – particularly those associated with Proof-of-Work protocols – should mobilize a conversation on the extractive industry and the promises of the green economy. Digital extraction helps bring these dynamics into focus by highlighting the incomplete nature of sustainability and responsibility initiatives, as extractive industries move toward a post-carbon future, and by helping reveal unequal forms of value extraction as these become increasingly draped in new digital technologies.

Acknowledgement

Filipe Calvão's research was funded by the Swiss National Science Foundation as part of the project "Transparency: Qualities and Technologies of Global Gemstone Trading" # 10001A_173354/1.Matthew Archer's research was funded by a Danmarks Frie Forskningsfond (DFF) Sapere Aude starting grant (#7023-00115AB) and was conducted as part of the SUSTEIN research project at Copenhagen Business School.

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