

Proceeding Paper

# Transparency with Blockchain and Physical Tracking Technologies: Enabling Traceability in Raw Material Supply Chains †

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† Presented at International Conference on Raw Materials and Circular Economy, Athens, Greece, 5–9 September 2021.

**Abstract:** By combining blockchain with physical tracking technologies, raw materials can potentially be traced throughout their global supply chains. Physical tracking technologies enable observing how raw materials move within the physical world, whereas blockchain translates these events into the digital world with an immutable record. This paper presents a taxonomy of different physical tracking technologies and examines if and how the combination of these technologies render raw material supply chains more transparent. Although academic literature highlights the theoretical benefits of combining these transformative technologies, large scale projects are still in their early stages. Following a brief literature review, this paper leverages an empirical approach to classify different tracking technologies, their fields of application and limitations, as well as how these technologies can enable supply chain transparency. Obviously, there is no single technology that can fulfil all requirements along complex supply chains. However, the relevant combination of respective technologies can help bridge gaps by increasing transparency within supply chains.

**Keywords:** transparency; supply chains; blockchain; physical tracking technologies; taxonomy; raw materials; Internet of Things; traceability; European Green Deal



**Citation:** Bacchetta, A.v.B.; Krümpel, V.; Cullen, E. Transparency with Blockchain and Physical Tracking Technologies: Enabling Traceability in Raw Material Supply Chains. *Mater. Proc.* **2021**, *5*, 1. <https://doi.org/10.3390/materproc2021005001>

Academic Editors: Anthimos Xenidis, Evangelos Tzamos and Konstantinos Simeonidis

Published: 15 September 2021

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## 1. Introduction

Digital technologies that aim to transform the mining sector are attracting increasing attention from industry actors, policymakers, and investors. Amongst all these transformative technologies, blockchain is perceived as a means to render the raw material supply chain more transparent [1]. Supply chain transparency is often viewed as the essential element for solving many of the current trade and logistics challenges. Especially concerning the raw materials sector, greater transparency is often expected to solve key issues by ensuring product provenance and enabling traceability along supply chains. In particular, decentralized blockchain technology may guarantee greater data security and offer the opportunity to create digital assets and information with a high degree of immutability and transparency [2]. Yet, how can one ensure that the information entered into a blockchain is accurate, timely, and relevant? This paper explores different core features of blockchain and physical tracking technologies that address the following research questions:

- How can blockchain technology, combined with physical tracking technologies, support supply chain transparency?
- How can physical tracking technologies be categorized and structured in view of their applications and limitations, in order to create a simple taxonomy that can be relevant for tracking raw materials along supply chains?

In order to illustrate the synergies between tracking technologies combined with the blockchain, we leverage our interpretation of the “internet of things” (IoT) and how

this can support traceability. The concept of the IoT, has been defined as a “network of interconnected electronic devices” [3]. An additional definition has been “a group of infrastructures interconnecting connected objects and allowing their management, data mining and access to the data they generate” [4]. Whereas the connected objects have been defined as “Sensor(s) and/or authenticator(s) carrying out a specific function and that are able to communicate with other equipment. It is part of an infrastructure allowing the transport, storage, processing and access to the generated data by users or other systems” [4].

Due to its key features, which will be described briefly in Section 3, a blockchain can serve such an IoT infrastructure for interconnected physical trackers to allow their management, data mining, and access to the data they generate. In Section 4, a description of the Minespider blockchain shall illustrate its potential to track raw materials and provide transparency along complex supply chains, also by integrating physical trackers. Section 5 then outlines a simple taxonomy of key physical tracking technologies that, when linked to the blockchain, can further enable transparency within raw material supply chains. Ranging from barcodes to satellite communications, this research analyses the benefits, challenges, and use cases for these tracking tools when linked to the blockchain.

These technologies are enablers of a broader trend, a global push for greater supply chain transparency and circularity by both practitioners and policymakers alike. For instance, the EU Commission is already pushing this agenda with the European Green Deal [5]. This is flanked by a Circular Economy Action Plan [6] and corresponding legislative procedures that are based on sustainability principles and mobilising the potential of digitalized product information. It shall include solutions such as digital passports, tagging and watermarks, as well as establishing a common European Dataspace for Smart Circular Applications with data on value chains and product information [6]. For example, the proposed regulation of the European Parliament and of the Council concerning batteries and waste batteries, is to promote “an electronic system that maximises the exchange of information, enabling tracking and tracing of batteries, provides information about the carbon intensity of their manufacturing processes, as well as the origin of the materials used, their composition, including raw materials and hazardous chemicals, repair, repurposing and dismantling operations and possibilities, and the treatment, recycling and recovery processes to which the battery could be subject to at the end of their life” [7].

As all IoT devices and tracking technologies generate big data, there is a rise of new business models, as well as more reliable data flows. A prominent example of this trend is SAVANT, a consortium by Earth-i, Marex, and ESA, who developed a business by taking video monitoring data from several different Earth observation satellites, to show and analyse smelter activity levels and to detect periods of shutdown or inactivity, and feed their daily assessments into global and regional indices to give consistent, insightful and dependable results [8]. Physically tracking the flow of raw materials from mines to smelters, and eventually to end-consumers, in combination with a blockchain system, can reshape global supply chains toward more responsible sourcing and enable circular processes.

## 2. Methodology

This study is embedded within an EU-funded research project for the blockchain company, Minespider AG [9]. Although the authors’ employment with the Minespider Group qualifies them as dependent, this positioning has enabled the authors to generate insights that encompass both the perspective of industry actors (such as mines, smelters, refiners, processors, manufacturers, transporters, traders, agents, etc.), as well as policymakers (such as the OECD, UNECE, WEF, HMRC, EU and some Member States, Industry Associations, NGOs, etc.) and other strong industry actors (such as Google, Cisco, Volkswagen, and others).

Concerning the applied research methodology, a pragmatic, mixed methods approach was taken [10]. This gave the authors the freedom to combine their own experience

from their development and operation of a blockchain, case studies, projects and tracking operations with online research and literature reviews, as well as qualitative interviews.

### 3. Blockchain and Tracking Technologies in the Raw Material Sector

Blockchain technology is frequently associated with cryptocurrencies, however its decentralized nature, its high degree of data immutability and its adaptability offers the potential for applications in a wide range of further use cases [11]. Both scholars and practitioners are increasingly focusing on blockchain's potential to enable supply chain transparency [12–15]. There seems to be a general expectation that introducing blockchain technology to supply chain entities can immediately create favourable conditions for supply chain transparency. However, the value of implementing blockchain technology not only depends on the design of the architecture, but also on the quality of data it holds in an immutable, or tamper-proof, fashion.

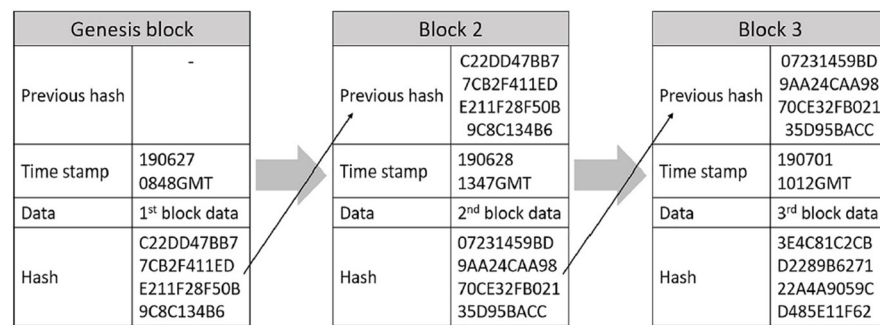
One approach to generate valuable, valid data can be to trace materials' journey through physical tracking technologies and input this data directly on the blockchain in order to keep an immutable record that can be distributed to downstream clients, assessed by auditors and added to along the supply chain. This indicates how the combination of blockchain and tracking technologies can become key enablers for supply chain transparency [16].

After explaining in the following section the general concepts of blockchain architectures in more detail, this paper will further explore how physical tracking tools and blockchain can be a supportive means to qualify product provenance and other environmental or social information within a more transparent raw materials supply chain. Whereas a simple taxonomy of physical trackers with a focus on raw materials will be elaborated in Section 4. Indeed, this paper's focus on raw materials and specifically the mining sector is particularly relevant due to the sector's reputation for opacity and cumbersome social and environmental standards [17].

#### 3.1. Blockchain Architectures

An essential element that can provide for the integrity of a blockchain architecture is that it is built on the distributed ledger technology (DLT) [18]. DLT means that an ordered list of transactions is replicated over multiple nodes [19]. Nodes are the instances that not only keep replicas of the data on the blockchain but also need to agree on an execution order of transactions [19].

As another essential element to provide for the integrity of the ledger and as illustrated in Figure 1, a blockchain establishes a consecutive chain of encrypted and hashed blocks of data, whereas every block is timestamped and immutably linked to the previous block by including a hash of the previous block [18]. In doing so, the blockchain technology takes advantage of an important distinction between encryption and hashing. Encryption is bi-directional: Data can be encrypted and decrypted. It always can be reverted back. Hashing is one-directional only: When a hash code is generated from data, this hash result is always the same. In case the respective data is modified, the generated hash code will be different. The same applies if encrypted data is hashed. The hash code generated from the encrypted data is always the same. Therefore, by comparing hash codes one can identify if the data matches or not (even if the data was encrypted).



**Figure 1.** Structure of a blockchain; Source: [12].

Because the users or owners of the nodes in a blockchain environment may not trust each other, its decentralized setup and an appropriate consensus mechanism ensures that the processing and replication of data is managed without depending on a trusted individual person or instance. And there is a growing variety of blockchain architectures that are usually designed in consideration and combination of the following principles and their variations [2,10,19,20]:

- The consensus protocol: for example, authorization and procedures to register and seal blocks are based on proof-of-work (PoW), proof-of-authority (PoA), proof-of-stake (PoS), proof-of-elapsed-time (PoET), or other variations or types of protocols [21]. These differing consensus protocols also determine the amount of energy a blockchain will consume in order to validate transactions.
- Node control: the governing structure to run nodes in a blockchain. For example, anyone can join to run a node in a public blockchain without further authentication, whereas in a private blockchain, every node is authenticated and its identity is known to the other nodes.
- Access control: for example, anyone may initiate or read transactions in a permissionless blockchain, whereas limitations may apply in a permissioned blockchain.
- Smart contract execution: depending on the specifications and rules of the blockchain environment to initiate automated execution procedures referred to as “smart contracts”, users may be allowed to customize transaction logics to suit their applications.

In the context of supply chain transparency and traceability along complex supply chains, the main benefits of the blockchain technology can be its high level of immutability and transparency, because it can create unique digital documents, whose manipulation can be immediately detected by independent participants, since the information is stored on different blocks that are time-stamped and interlinked in a way that one block can't be modified without effect on the other blocks in the chain. These characteristic features of blockchain technology appear particularly suitable for creating transparency within complex supply chains, where collaboration across multiple supply levels is challenging due to a lack of knowledge or trust between suppliers.

However, key limitations compared to other database architectures are:

- Level of complexity [19]: Depending on the design of the consensus mechanism and other components of the blockchain environment, this can generate greater complexity compared to usual database architectures.
- Level of immutability: Depending on if and how the consensus mechanism and the further setup of the architecture restricts a change of data, the limitations to delete or modify data can be an issue with regard to legal requirements stipulated by applicable laws and regulations or by contracts. Also, it may not meet the individual user requirements or expectations [22,23].
- Level of transparency: Depending on the architecture, and in particular, in combination with the level of immutability, a high level of transparency and a limited flexibility on that level can again be an issue with regard to legal requirements stipulated by

applicable laws and regulations or by contracts. Also, this missing flexibility may not meet the individual user requirements or expectations.

- Level of throughput, latency and scalability [19]: The design and the complexity of the blockchain architecture, and particularly of the consensus mechanism, can result in limitations in throughput, latency and scalability of the blockchain environment. In the context of tracking technologies, such limitations need to be considered in detail and can be a key impediment. For example, due to its latency and limited throughput, a blockchain architecture may allow others to immutably store recordings of live events, but it is not capable of displaying live events itself.

### 3.2. Minespider's Blockchain

To illustrate a blockchain that has been designed for supply chain transparency and collaboration along complex supply chains, Minespider's blockchain shall be outlined in more detail:

Minespider developed a public, permissioned blockchain using GETH [24] nodes and a proof-of-authority consensus mechanism that connects supply chain data and documents by encrypting them in linked, digital certificates (also referred to as "product passports"). An essential feature of Minespider's type of public-permissioned blockchain is that everyone can have access to the public blockchain, but only nodes that have been accredited to the consortium are authorized to seal blocks. If a new sealer requests to be accredited, a vote takes place and with 50%+ of the votes the new account gets accredited.

Minespider has frontend applications and templates for manual use, as well as APIs for process automations. Minespider is data agnostic in the sense that input data of any format can be included in a product passport and secured in an immutable way on blockchain and to be shared along a supply chain. This can, for example, include pdfs, images, videos and other formats of documentation. It can also include input of any format generated by physical trackers. Product passports include an individual QR code that can be scanned by standard scanning tools (e.g., via a smartphone) to provide access to the public data associated with the passport and to request permission to access secured data. These QR codes can be printed and affixed to shipments, or laser printed directly onto the materials themselves. Moreover, product passports provide a proof of provenance and a chain of custody along a supply chain. This way the Minespider infrastructure can help to bridge gaps resulting from the combination of different sources, or stages of production, and also to enable a circular economy.

To balance the requirements of transparency and confidentiality along a supply chain, Minespider provides tools to easily manage different layers of confidentiality and transparency according to the respective needs of participants along complex supply chains. Information that is assigned to the public layer is visible to anyone. Information a user assigned to the private layer is visible to the immediate contractual partners only, whereas the transparent layer is visible along the respective supply chain(s).

To support the different layers of transparency, Minespider works with nested hashes. This means that separate hashes are generated from encrypted data and in accordance with the respective layer the data has been assigned to by the person who uploaded and filed that data. The hash codes of data that are stored in the respective transparency or private layer, are hashed again and stored in the public layer, which again is stored on the blockchain. This way, Minespider can provide that everyone can see, compare, and validate data on the public layer. But to be able to decrypt and see the data that was assigned to the private or transparency layer requires the respective authorization(s) and key(s) to decrypt and read this data. Minespider's blockchain provides for greater legal compliance and a high level of throughput and scalability at low latency.

### 3.3. Considerations on the Value of the Data in a Blockchain Environment

To assess the full value of a blockchain environment, it is important not only to analyse the technical infrastructure, but also the content that is captured or made available via this infrastructure. In this respect, two different aspects can be considered:

First of all, the value of the individual dataset can be assessed. In this respect, the value of the data stored on or referred to in a chain of blocks is only as good as the quality, in particular the veracity of the information entered into the blockchain. This leads to the classic “garbage in, garbage out” dilemma of many databases, meaning that the value of the output of data equals the value of the input of data. This understanding is based on the assumption that if the data that is introduced to the blockchain is of low value, for example because it is incorrect or incomplete, then the value of the data output of this blockchain can't be higher. And the usual reflex to this dilemma is that there should be sufficient checks of the accuracy and completeness of the input already at the beginning, when or before the data is introduced to the blockchain.

However, the aforementioned approach does not cover the full potential of the blockchain. Because two essential elements of a blockchain, which can have a strong impact compared to traditional databases, have to be considered sufficiently: The high degree of data immutability and transparency that a blockchain can provide (depending on the design of the architecture) can have an indirect effect on its content, too. When there is no chance that data can be changed undetected by others, then the time of the data check does not necessarily always have to be right at the beginning when the data is first recorded. Blockchain technology can therefore lead to greater flexibility in the timing of data verification. The purpose as well as the need or effort required for the validation may also play a role in this respect.

If data has been manipulated after it was added to the blockchain, it can be detected by comparison with the original blockchain data. This not only increases the risk for manipulators accordingly, but also for those who may want to later claim (incorrectly) that data was manipulated by others further along the chain. Finally, immutability and transparency can enable data validation at a later point in time, highlighting when and by whom the data was first introduced into the blockchain, because since then every edit to the data is immutably tracked.

All in all, the immutability and transparency of blockchain technology can generate a high degree of trust for information stored on-chain. Yet the issue of how to enter trusted data into the blockchain, leads us to consider tracking technologies in more detail.

## 4. Suggested Taxonomy: Tracking Technologies to Effectively Capture and Input Key Data on the Blockchain

Within this paper, we consider the majority of tracking technologies to be part of the IoT ecosystem and suggest a taxonomy with their key features, benefits and use cases in the mining industry. Although technologies such as markers and QR/Barcodes are not necessarily electronic devices, they can integrate with other IoT objects and provide or qualify a digital identity. The common element connecting all these technologies is that they include functionalities that can capture and communicate granular, timely, relevant and accurate data, which can be automatically or manually entered into the blockchain.

We have analysed the following most common physical tracking methods which will be described and exemplified in more detail below:

- Video monitoring (Table 1)
- Bar and QR codes (Table 2)
- Markers and taggants (Table 3)
- Cellular, near range and low power network tracking tools (Table 4)
- Satellite network tracking tools (Table 5)

In a further step, we examined and classified the aforementioned technologies with respect to certain characteristics that are generally particularly relevant for physical tracking. These are the following characteristics:

- **Robustness:**  
Robustness usually needs to be considered in the context of the processing of raw materials. During their lifetime, many materials are exposed to high temperatures, pressures or other influences. For example, ores and other metals often are heated, smelted, pressed during processing. This brings up the question if the tracker in question can stand the respective transformations.
- **Range:**  
Range usually needs to be considered in the context of the implementation of the IoT environment, both in terms of the inputs the tracker can capture, as well as the access to the data it produces. For example, in some areas of operation, there may be no wired direct access to a network on which to transmit or receive data.
- **Energy Requirements:**  
Energy requirements usually need to be considered with the accessibility and lifetime of the tracker. Often the energy requirements go with the range of the tracker. Certain use cases may require flexibility, or operate in areas where access to a wired grid is not available, for example in deserts or underwater.
- **Data Related Capabilities and Limitations:**  
These usually need to be considered in terms of the kind and volume of data input and output the tracker can manage. For example, trackers like video cameras may generate large data volumes that need to be transmitted and processed.
- **Other aspects for consideration such as costs and complexity to implement, legal requirements, and so forth.**

Furthermore a description of typical use cases highlights the context and applications within this topology.

**Table 1.** Characteristics of Video Monitoring.

Typical Use Cases	Video monitoring is a very common way to track activities on properties or in facilities. In the mining industry, it can be used to track movements of loads and machinery, as well as other operations and their environmental impacts. It can be used in open pits and other large environments on the ground, but also in underwater operations. It is typically used to monitor the exploitation and delivery of large volumes like bulk material. It is used in fixed installations as well as in combination with movable technology, such as drones, planes or satellites (see also Table 5 below). Video monitoring can also be combined with an automated evaluation of the image material to trigger further events [8,24]. For example, in ports the incoming deliveries of containers can be tracked per video monitoring while image and text capture software can identify container-related data.
Robustness	Video technology can be quite robust and used even in harsh environments. Although, like most technical equipment, if there is no protective encapsulation, there can be limitations to withstand excessive temperatures, dust, humidity, vibrations or other impacts.
Range	Video technology can be used to monitor objects in and from various ranges. Often it is used to monitor the direct vicinity, e.g., by fixed installed cameras, but, as mentioned above, wide distances can be covered. This then usually depends on supportive technology to bridge the distances, such as cellular or satellite technology to transmit the image material (see the respective chapters below).
Energy Requirements	The energy requirements for video monitoring can depend on multiple aspects, in particular the volumes and distances that need to be covered. Where wired power is not possible or practical, battery or solar powered installations and appropriate consumption management may be used.
Data Related Capabilities and Limitations	Large volumes of data can be generated during the capture and further processing of video footage. This in particular can be the case with live monitoring of events. However, as mentioned above, due to latency and capacity limitations of blockchain architectures (in particular due to time needed to achieve consensus for validating data on a blockchain) such limitations may conflict with the requirements for live monitoring.
Other Aspects	Video monitoring technology usually can be provided at reasonable costs. However, in cases where personal data, such as biometric information and other sensitive data is involved, legal limitations or obligations such as the General Data Protection Regulation (GDPR) need to be considered. In particular, legal requirements to modify or delete data may be an issue if the blockchain environment would not allow it to meet such requirements.

**Table 2.** Characteristics of Barcodes and QR Codes.

Typical Use Cases	A barcode is a machine-readable optical label that contains information about the item to which it is attached or assigned to. A QR code is a matrix type of barcode. The use of bar and QR codes is mostly associated with fast moving consumer goods for supermarket check-out, but is also widely used in the early stages of the supply chain. Within the mining industry, barcodes and QR codes can, for instance, be attached to bags of ore, ingots, and even containers to identify specific lots and verify provenance [25]. Moreover, unlike RFID labels for example, bar- and QR codes can be generated and distributed electronically, e.g., via e-mail or mobile phone.
Robustness	Barcode and QR codes usually are quite robust. For example, certain materials may allow that the bar or QR code is directly laser-printed on the material. Thus the robustness often correlates with the material of choice. This also means that a smelting procedure can interrupt the tracking of objects that are labeled with a laser-printed barcode or QR code.
Range	The range of a barcode or QR code is limited to its visibility, unless it is transmitted by supportive means. It requires a scanner or other reader to read the code and translate it into data for further processing.
Energy Requirements	Besides the energy needed to print and read the code, there are usually no further energy requirements.
Data Related Capabilities and Limitations	The data capacity of the barcode or QR code may be limited, depending on the type of code and the standard(s) applicable to it, for example in terms of data type, version and correction level. But usually it is used just to link to the relevant information via an URL. Problems can relate to difficulties reading a barcode or QR code, for example due to errors in code printing, surface contamination, water, humidity, varying lighting levels [3].
Other Aspects	Barcode and QR code solutions both can be relatively low cost and low tech, which can make them very practical concerning most use cases for raw materials tracing and sourcing scenarios. However, to provide visibility and compatibility with the applicable standards, barcodes and QR codes require a minimum space to be printed on. This can exclude them from being printed directly on bulk material or material of smaller size. A solution to this may again be bags or other containers.

**Table 3.** Characteristics of Markers and Taggants.

Typical Use Cases	Taggants are chemical or physical markers that are added to materials, which enables them to be tested for authenticity. In this way, they also mitigate risks for counterfeiting and forgery in products. There are several types of taggants/physical markers, and are generally microscopic particles. They are added to the materials in small quantities and are easy to detect with a “reader” mechanism. Markers can combine visible or concealed security features and have several form factors, such as DNA encoded information, or micro-dust made out of ceramics or diamonds that can withstand harsh processing treatments within the supply chain. Similarly to the unique fingerprints of humans, taggants can go beyond the level of barcodes since they can provide objects with an identity that cannot be tampered with [26]. A multilayer taggant system has been described based on phase change nanoparticles of metals and eutectic alloys, which can be added in matrix materials and printed on objects to form microscale features containing fluorescence and thermal signatures [27]. The fluorescence additive could be used for initial screening. Micro features could add an extra layer of protection, and phase change nanoparticles could be used for high capacity serialization or forensic investigation [27].
Robustness	Chemical taggants, biological taggants, DNA taggants and isotope ratios may be too sensitive to the environment, may degrade over time, and may only function over a limited period of time [27]. They often may not stand smelting processes of raw materials. However, as mentioned, some markers or taggants, such as micro-dust made out of ceramics or diamonds, can withstand harsh processing treatments. Also, a durable colored polymer sandwich can be capable of surviving detonation events of explosives. The color sequence of the requisite layers can determine the origin and ownership of the materials [26].
Range	Depending on the type of marker or taggant and the detection method, the ranges and performances can vary.
Energy Requirements	Besides the energy needed to generate and detect the marker or taggant, there are usually no further energy requirements.



**Table 3.** *Cont.*

Data Related Capabilities and Limitations	Often the data related capabilities of markers and taggants may be limited. DNA, as the building block of the genetic code, has the advantages of almost unlimited coding capacity for unique identifications and relatively cheap synthesis for taggants. However, the verification of DNA requires labour intensive sequencing of the DNA taggant [26]. Spectroscopic tagging can allow for high-throughput through verifying measurements via spectrophotometry [26].
Other Aspects	Although the technology on which markers are based is mature, their use in raw materials supply chains for traceability and transparency purposes is still in the early stages and may be relatively costly. To enhance the security level of labeling, multilayer taggants that contain fluorescent, microscopic features and numeric code sequence may be used [27]. These solutions may be complemented with biochemical fingerprinting solutions to cross-check authenticity.

**Table 4.** Characteristics of Cellular, Near Range and Low Power Networks.

Typical Use Cases	A vast array of radio frequency-based technologies enable tracing of materials both on production sites, such as mines, as well as throughout global supply chains [28]. RFID tags combined with sensors are widely used to measure everything from location to temperature conditions for tracked goods [29], [12]. One can distinguish between tracking technologies that are designed for short range applications such as NFC (Near Field Communications) to large networks using low power such as Sigfox or LoRa (Low Range). The emerging 5G networks can create an additional layer for tracking use cases as they were designed to further enhance the IoT with larger data volume capacities and autonomous vehicle applications.
Robustness	The robustness of the power networks depends on the type of network and the devices involved. Some may be encapsulated to withstand harsh environments, but usually there are limits to be considered. For example, RFID tags or other senders usually will not withstand a smelting process.
Range	The various technologies often differ significantly in their range and performance. Unlike a barcode, a sender may not always be required to be within the line of sight of the reader, so it may be embedded in the tracked object. For example, an RFID device inside a box or other container may be readable from outside without a need to open the box or container. However, there may be performance variations, too [3]. NFC communication usually has a range of a few cm only, whereas Sigfox or LoRa can enable long-range transmissions with low power consumption to bridge the gap to more energy intensive long range networks, such as 5G, 4G etc.
Energy Requirements	Passive devices, such as some types of RFID, can be powered by energy from the reader's interrogating radio waves. Active devices require their own source of power, for example a battery. This is why active devices usually can be read at a greater range.
Data Related Capabilities and Limitations	Depending on the technology used, devices can be read only or include a fixed or programmable logic for processing and transmitting and/or receiving data. In cases where the technology responds strictly sequentially (like with some types of RFID devices), managing bulks of items may be an issue, because the time needed for bulk reading can grow linearly with the number of devices to be read. Depending on the granularity of the tracking and the content that is tracked, data protection requirements need to be considered, too. For example, tracking of movements of goods per RFID, NFC, GSM or other technology may also allow direct conclusions to be drawn about the movement or performance of persons involved with the handling of the tracked goods. Moreover, depending on the type of technology, eavesdropping may be an issue. For example standard plain NFC may not be protected against eavesdropping and data modifications.
Other Aspects	A variety of standards have been developed for various use cases to provide compatibility and safety. Although implementing and using these networks for tracking objectives can be costly, some of their features such as roaming across borders are key benefits when tracking global supply chain journeys. Moreover, the low latency rates of 5G are expected to enable new business models to emerge for the IoT ecosystem with potential new tracking applications.

**Table 5.** Characteristics of Satellite Technologies.

Typical Use Cases	Small satellites in low orbits allow mobile means of transportation such as trucks, airplanes, and ships to continuously stay in contact throughout their journeys, by providing updates on location, as well as external conditions. One of the most used satellite systems for shipment tracking is “AIS” (automatic identification system). This automatic tracking system uses transceivers on ships for vessel traffic services. Its main goal was initially to avoid accident collisions and aid ship navigation. However very rapidly the potential for using the AIS satellites for fleet and cargo tracking seemed apparent. Furthermore satellite imaging can provide almost real time information about events happening in the field, especially in areas that are geographically remote such as open air mines [30–32]. As already mentioned in the introduction, video monitoring data from several different Earth observation satellites, is used to show and analyse smelter activity levels and to detect periods of shutdown or inactivity [8]. Also drones can complement these real time observations and insights with additional aerial imaging.
Robustness	Usually the robustness of the satellite is no issue. However, the data connection to the satellite may be subject to limitations.
Range	Obviously, communication with a satellite can cover long distances. The resolution can be relatively high. However, clouds and other weather conditions, volcanic eruptions or other incidents may have an impact on imagery, spectrography or other procedures and the respective quality of the data.
Energy Requirements	The satellites can be powered by built-in photovoltaic modules.
Data Related Capabilities and Limitations	In terms of imagery, there is a classification of five types of resolution: spatial (image size representing a size of surface), spectral (wavelength interval and number of intervals), temporal (time of image collection periods for a surface location), radiometric (levels of brightness and bit-depths of sensors) and geometric (capability to effectively image a portion of surface in a pixel). Because of relatively high resolutions, satellites can generate huge volumes of data. Depending on the technology and the altitude of the satellites, resolutions can vary. It can take an effort to process and create useful data from the raw data. Privacy regulations may also need to be considered. As mentioned, the quality of the data may be impacted by weather conditions, volcanic eruptions, or other incidents. By combining satellite imagery with vector or raster data from geographic information systems, the imagery can be spatially rectified to gain compatibility with further data sources.
Other Aspects	Smaller low-orbit satellites can be more cost-effective and are transforming the field of supply chain visibility and transparency. Recent advances in satellite imaging, data processing, and machine learning are opening new doors to monitor activities within supply chains in almost real time as well as rendering the cost of accessing geospatial data more affordable.

## 5. Discussion and Conclusions

The findings of the research outlined in this paper explain how the combination of blockchain and tracking technologies can contribute to improvements in supply chain transparency and traceability, by feeding key data from IoT devices directly into the blockchain. The proposed simple taxonomy of physical tracking technologies provides guidance for understanding the different application areas, requirements, and limitations of physical trackers. It turns out that different physical trackers can be of use depending on the application and material, the processing stage, and other particularities of the supply chain. In this context, blockchain technology can help not only to secure data entered manually or automatically from IoT devices, but to merge the data generated by the variety of trackers along the supply chain in a tamper-proof manner. Blockchain technology can also be designed in such a way as to balance the needs for transparency with the need for confidentiality of the different stakeholders along the supply chain. Although this paper illustrates how these transformative technologies render raw material supply chains more transparent, some questions still remain. The limitation of this research paper resides in its inability to address the throughput, latency, and scalability issues inherent in blockchain technology, which pose a significant issue as trillions of data points from IoT devices will need to feed into the blockchain annually. Furthermore, this paper does not deal with artificial intelligence to assess, organize, and extrapolate further results from datasets [33]. However, this paper does illustrate how these transformative technologies can be used in

unique combinations to capture and communicate supply chain data in a more accurate, granular, relevant, timely, and trusted manner than was possible with their separate usage.

**Author Contributions:** Conceptualization, methodology, investigation and writing—original draft preparation: V.K., A.v.B.B.; writing: review and editing: E.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** The employee and the projects the authors were involved with received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreements No. 946437 and 957110 as well as from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, under project agreement No. 19458-CLC-C-2020-8.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Conflicts of Interest:** The authors declare a conflict of interest due to their employment and participation in projects of Minespider AG and Minespider Germany GmbH and the aforementioned funding.

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