Attributes of Commodity Supply Chains: Feasibility of Blockchain Technology for Responsible Sourcing

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Assuring the credibility of information on sourcing of raw materials is a major challenge in sustainable supply chain management. Enhancing the reliability and transparency increase the trust of stakeholders and help mitigate sustainability risks that may cause reputational harm to firms. Blockchain is an emerging digital technology that has gained interest as a tool for assurance of supply chains. This research explores the potential for blockchain technology to contribute to the domain of sustainability, looking at the feasibility of blockchain technology for responsible sourcing. The study employed a qualitative approach, drawing on data from expert consultations, academic literature, industry reports and media reports to evaluate the attributes of commodity supply chains that could influence their assurance and alignment with blockchain. A framework was developed to analyze the attributes of commodity supply chains relevant to blockchain technology. A major contribution of this study is the development of a decision tree tool that was then used to assess twelve different commodity supply chains for seven biotic commodities (cocoa, coffee, cotton, fish, palm oil, oranges, and rubber) and five abiotic commodities (aluminum, cobalt, diamonds, mica, and tin). Significant sustainability risks in these commodity supply chains were identified. The results found that there is commonly a lack of trust among actors in all the assessed commodity supply chains yet found variation in the willingness of different sectors to accept new technology. Two models (a hybrid model and a digital model) are proposed that could be used by companies interested in transitioning to a blockchain-based assurance system. The findings in the study provide new insights into the practicality of blockchain technology in sustainable supply chain management.

Keywords: assurance, blockchain, supply chain auditing, sustainable supply chain management, sustainability risks, responsible sourcing, traceability

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Chapter 1: Introduction

1.1 Background and Context

Global demand for commodities has increased over time due to increasing affluence and material consumption (Schandl et al., 2018). Concern over the supply of commodities has risen due to environmental and social issues raised by consumers and human rights activists. Reports of human rights violations and poor management of natural resources have made them the target of non-governmental organizations (NGOs) and have led to reputational harm to firms (Doh & Guay, 2006).

With globalization, the complexity of commodity supply chains has increased, presenting sustainability risks in the supply chain (Christopher & Lee, 2004). Hofmann et al. (2014) defines sustainability risk as "a condition or a potentially occurring event that may provoke harmful stakeholder reactions to the company" (p.168). Even though most of the sustainability risks are present at the upstream of the supply chain, downstream companies are often at a higher risk of reputational losses due to a strong association of products with the downstream brand (Kovács, 2008).

Various scandals reported in the past concerning responsible sourcing of raw materials raise concerns about the legitimacy of the information presented to the stakeholders (Guo et al., 2015). For example, leading brands like Zara and H&M have faced criticisms for sourcing products from companies that maintained unethical working conditions and poor environmental practices (Siegle, 2012). The level of integrity across supply chains is thus unclear, and the scope of potential fraud puts downstream companies at the risk of losing credibility due to a lack of transparency.

With an increasing number of firms committing to corporate sustainability, stakeholders are demanding assurance services to enhance the quality and reliability of information related to sustainability performance (Coram et al., 2009). These assurance services provide credibility and act as a sustainability framework for firms to follow while reviewing non-financial information. Many firms are considering novel technologies for assurance in an attempt to mitigate social and environmental concerns raised by stakeholders (Bierbaum et al., 2020).

Blockchain, the digital technology behind cryptocurrencies, has received attention for its potential to assure provenance by creating traceable and transparent supply chains (Abeyratne & Monfared, 2016). Benchoufi & Ravaud (2017) describe blockchain as a "huge, public, secure and decentralized datastore of ordered records, or events, called blocks" (p.2). Responsible sourcing in supply chains has emerged as an area where blockchain could potentially make an impact. For example, IBM and Responsible Minerals Initiative (RMI) have projects in place for using blockchain to maintain traceability. However, the efficacy of digital technology like blockchain in sustainable supply chain management is still unclear.

1.2 Objectives and Research Question

In recent years, blockchain technology has gained attention as a tool that can be used to increase the transparency of supply chains. However, there exists a need to explore the benefits of blockchain to sustainable development and to consider its value to sustainable supply chain management. Therefore, the overarching purpose of this research is to explore the contribution of blockchain technology to the domain of sustainability.

1.2.1 Research Objective

Various studies have shown that blockchain technology can increase transparency in supply chains by recording information in a way that it is visible to multiple parties (e.g., Abeyratne & Monfared, 2016; Casado-Vara et al., 2018). However, previous studies have not shown how the attributes of commodity supply chains relate to blockchain technology. To address this gap, this research aims to identify generic attributes of commodity supply chains that make them easier or harder to assure with blockchain technology. Although work has been done elsewhere that considers the complexity and ability to effectively assure individual commodity types, a further objective of this study was to consider and compare sustainability risks and assurance possibilities across multiple and diverse commodities including food, fibres, metals and minerals.

1.2.2 Research Question

Several industries are proposing the use of blockchain technology for digitizing transactions in supply chains (Cox & Zhou, 2019; Knapp, 2019; Pollock, 2020). However, there needs to be an understanding of the attributes of commodity supply chains that make blockchain technology appropriate for responsible sourcing.

To fulfill the purpose of this thesis, this study aims to answer the following research question: ***What attributes of commodity supply chains make them amenable to blockchain solutions?***

1.3 Significance of the Problem and Contribution of the Study

Companies seeking to prevent reputational losses are highly dependent on auditors who provide strategic information about suppliers (Short et al., 2016). However, the extent to which current assurance services are effective is debatable. According to Pohlen (2003), existing assurance mechanisms capture intrafirm performance as opposed to inter-firm performance due to lack of visibility across supply chains. Current verification procedures involve auditors using paper based systems or electronic databases that do not provide information beyond the company's borders (RSB et al., 2018).

In current assurance mechanisms, there is a lack of consistency. Auditors using their judgement to verify compliance of a firm to standards can result in inconsistent interpretations and assessments (Castka et al., 2020). There is also a possibility of corrupt auditors who could be biased which can affect the accuracy of data that is presented to the stakeholders (Castka et al., 2020). Additionally, research has confirmed that auditors might not always be competent to perform verifications on environmental disclosures and sustainability reports (Short et al., 2016). Thus, there needs to be an evaluation as to how better assurance processes can be established. Blockchain technology is one strong possibility for use as an assurance tool for responsible sourcing in supply chains, to track the flow of goods across the supply chain.

Previous research on blockchain has been mainly focused on its applications in finance and related domains. From the literature, it was identified that 80.5 percent of research papers on blockchain refer to Bitcoin (Yli-Huumo et al., 2016). Hence, the use of blockchain for sustainability applications remains largely unexplored. This study, therefore, aims to fill this gap in the literature and generate new insights into the applications of blockchain technology in sustainability by focusing on responsible sourcing in supply chains. This study explores the generic attributes of commodity supply chains that could potentially influence the adoption of blockchain technology as an assurance tool. Using a decision tree tool that was developed as part of the study, this research helps in identifying the specific commodity supply chains that may be amenable to blockchain solutions. This study also provides an overview of the various challenges faced in adopting this technology along with potential solutions to mitigate these concerns.

Chapter 2: Literature Review

This chapter explores academic literature on blockchain technology, supply chain attributes, and sustainable supply chain management. This literature review also seeks to examine the initiatives to ensure responsible sourcing in various industries. Furthermore, this review provides an overview of past studies that have addressed traceability in supply chains using blockchain technology.

2.1 Blockchain Technology

Blockchain is a digital, distributed ledger for storing transactions securely and transparently that is tamper-proof (Abeyratne & Monfared, 2016). With blockchain technology, users can trust the outcome of the system without trusting any individual participants (Werbach, 2018). Blockchain establishes trust by relying on cryptographic protocols rather than intermediaries or third parties (Werbach, 2018). It gained popularity in recent years with its successful application in Bitcoin. The transactions in blockchain are verified through a consensus mechanism involving the majority of the participants on the network (Crosby et al., 2016). New transactions are added to the end of the main blockchain with a timestamp, which ensures the integrity of the data (Nakamoto, 2008). Once all the nodes validate the data, the distributed ledger cannot be modified or deleted (Nakamoto, 2008). Furthermore, blockchain ensures that any participant can maintain a copy of the ledger (Swan, 2015).

The key properties of blockchain technology that facilitate its application in various sectors are transparency, immutability, decentralization and integrity, which are described in detail below (Wüst & Gervais, 2018).

Transparency allows the users to validate the information in the ledger, which can prevent fraudulent practices. By allowing users to verify the authenticity of transactions, blockchain technology can help in increasing customers' trust (Wüst & Gervais, 2018).

Immutability is a key property of blockchain technology that secures transactions from being tampered with. Each block in the chain is immutable because any change made to a block will invalidate all the other blocks downstream as they are connected (Saberi et al., 2018). This makes it impossible to change a block once boarded on to the blockchain, making information secure (Wu et al., 2017).

Decentralization eliminates the need for trusting third parties or intermediaries. The blockchain system is fairer due to the absence of intermediaries and the use of a consensus mechanism for the validation of transactions (Bashir, 2017). This property of decentralization helps in building trust by preventing the concentration of power.

Integrity of information ensures the protection of data when blockchain technology is used. This is because users can verify data through an auditable trail. Data is also secure compared to current technologies because every user receives a copy of the ledger, which can be used to prevent malpractices (Saberi et al., 2018).

Based on the access of data, blockchain technology can be classified into the public blockchain, private blockchain, and hybrid blockchain.

In a public blockchain, all participants have access to data and have permission to issue transactions. Furthermore, users can participate in the process of consensus and verify transactions while remaining anonymous (Lin & Liao, 2017). The most common examples of public blockchains are Bitcoin and Ethereum (Wüst & Gervais, 2018).

In a private blockchain, access to data is limited to certain participants based on a predefined group of nodes. Private blockchains use a less decentralized consensus mechanism as users are known to each other (Swan, 2015). A common example of a private blockchain is Hyperledger (Dinh et al., 2018).

Hybrid blockchain is a combination of both public and private blockchains where the public blockchain acts as a mainchain. The public blockchain is linked to several private blockchains through shared nodes (Summerwill & Khatchadourian, 2017). In this way, the advantages of both public and private blockchain are combined, which facilitates communication between different chains. Currently, hybrid blockchain solutions are still in the development phase.

The operation of blockchain technology can be explained based on consensus mechanisms (Gao et al., 2018). The most commonly used consensus mechanisms are Proof of Work and Proof of Stake.

Proof of Work is the most popular consensus mechanism and uses the solution of puzzles to establish the credibility of information (Dai & Vasarhelyi, 2017). Calculation of proof of work is known as mining, which involves trial and error to generate a valid solution. Once the puzzle is solved, the solution is broadcasted to other nodes to achieve consensus, which increases the validity of presented information and provides assurance (Dai & Vasarhelyi, 2017). Any change made to a block will require a new proof of work which makes it difficult to carry out fraudulent practices. However, proof of work is computationally expensive, which presents a major disadvantage (Chitchyan & Murkin, 2018).

In proof of stake mechanism, the nodes with sufficient stake get randomly selected as validators to forge a transaction (Gao et al., 2018). This process is fast as any node with enough stake can create new blocks immediately. Users lose their stake and ability to forge in the future if a fraudulent transaction is validated (Li et al., 2017). This ensures that only valid transactions are approved and discourages malicious activities on blockchain networks. Using a Proof of Stake system is also energy efficient as only a limited number of nodes are necessary to validate a transaction. Despite these advantages, there is a potential risk of the system being unstable if all the users have a sufficient stake or if no one has a stake (Gao et al., 2018).

2.1.1 Structure of Blockchain

Every block contains a list of transactions that are recorded and combined (Bahga & Madisetti, 2016). Each block is connected to its previous block through a unique hash, which serves as a fingerprint to validate data (Swan, 2015). A hash is an output of fixed length formed from data of arbitrary length, which acts as input (Franco, 2015). Since these blocks are linked to each other, forming a chain, any change made to a block can result in a random hash (Bahga & Madisetti, 2016). This forms the basis for ensuring immutability and protects the integrity of the data.

To modify a transaction in a particular block, a hacker would have to change data in all subsequent blocks as their hash would also change (Bahga & Madisetti, 2016). Furthermore, since blockchain technology is a distributed ledger technology, every user has a copy of the ledger (Swan, 2015). This means that when a new transaction is created, all the nodes can view and validate that transaction (Swan, 2015). Every transaction is recorded in a time-stamped log that is shared among all participants making it easier to detect fraud practices (Bahga & Madisetti, 2016). Hence, using blockchain technology ensures transparency, immutability, and integrity of data.

The hashing of data in a blockchain can be explained using a Merkle tree. Merkle tree helps in validating large amounts of data by distributing it into smaller parts for verification of integrity (Chitchyan & Murkin, 2018). A Merkle proof consists of a root hash, which is the hash of the entire tree and branches connecting the lowest tier of hashes to the root hash (Nakamoto, 2008). The simplest form of a Merkle tree is a binary Merkle tree, which is represented in Figure 1. Using a Merkle proof, it is possible to verify the authenticity of a transaction by checking a subset of the hashes rather than the whole data set (Chitchyan & Murkin, 2018). Hence, using a Merkle proof decreases the memory required for the process of verification by checking smaller amounts of data (Patel et al., 2017).

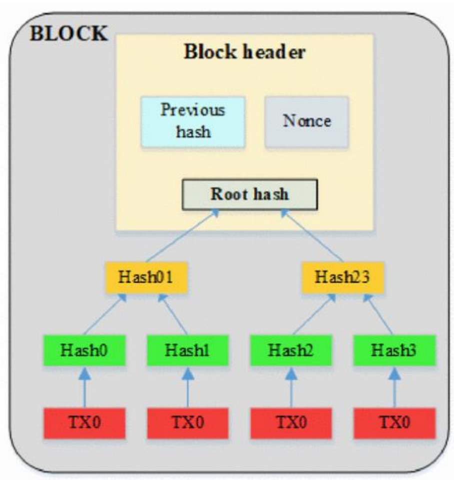

Figure 1: Binary Merkle tree. Adapted from 'Blockchain exhumed' by Patel, Bothra, & Patel, 2017, p.3

Smart contracts are programs within the blockchain that facilitate online exchanges while maintaining transparency, validity and trust (Ryan & Donohue, 2017). They are automatable agreements based on a commonly agreed logic (Henly et al., 2018). Smart contracts help in speeding up the transaction of assets traded in a blockchain environment by automatically executing it based on an agreement (Ryan & Donohue, 2017). In the case of Bitcoin, a smart contract is an algorithm that enables the transfer of a certain amount of money from one party to the other (Cuccuru, 2017).

2.1.2 Limitations of Blockchain Technology

Regardless of the numerous benefits of blockchain technology in various industries, there are limitations. Even though blockchain technology ensures transparency and immutability of data, human actors who record information on a blockchain can commit fraudulent practices (Werbach, 2018). This issue can lead to inaccurate data being entered, which can undermine the trust of users. Hence, though blockchain technology is secure, it can be exposed to vulnerabilities outside the ledger system. To mitigate this problem, each transaction should be verified before entering it into the blockchain system to ensure the accuracy of data (Apte & Petrovsky, 2016). Verification of transactions can be time-consuming, but this step is necessary to prevent the falsification of data stored in the ledger at a later stage.

The significant cost involved in adopting blockchain technology is another limitation. The calculations for solving the puzzle in proof of work require massive computational power, which translates to increased costs (King & Nadal, 2012). Additionally, the cost of hardware required to run proof of work algorithms is high (Cocco, Pinna, & Marchesi, 2017).

When a miner controls more than half of the hashing power, there is a risk of ‘51% attack’ in the blockchain, which is a limitation (Aitzhan & Svetinovic, 2018). Such a miner can create the longest chain on a blockchain network by mining faster than other counterparts (Aitzhan & Svetinovic, 2018). ‘51% attack’ in blockchain generally occurs when the incentives for miners reduce, due to which the mining network power falls. In instances where there are two conflicting versions of information stored in a blockchain, the network will choose the longest chain (Xu et al., 2017). This poses a major risk as the legitimacy of data stored in the blockchain is undermined.

It is also important to consider the issue of user acceptance with a blockchain solution (Baur, Bühler, Bick, & Bonorden, 2015). The public needs to know about blockchain as the system by design is decentralized and highly dependent on end-users in comparison to trusted intermediaries (Li et al., 2019). It should also be noted that blockchain solutions are still in the development phase, which can prevent companies from using this technology due to a lack of trust in the quality of services.

The scalability of blockchain also presents a barrier that could hinder the adoption of this digital technology. Currently, only one new block can be added to the chain every ten minutes, which reduces the volume of data that can be processed by blockchain in comparison to traditional transactional networks (Abraham et al., 2016). Hence, improvements in the efficiency of blockchain systems are essential to ensure their widespread deployment.

The legal issue is another major factor affecting the implementation of blockchain technology in various sectors (Werbach, 2018). In the event of a fraudulent transaction, it can be difficult to settle disputes due to the absence of a centralized governing body. Hence, decentralization, which is a key property of blockchain technology, can be a limitation in such cases.

Security risks due to leakage of data may be a concern while using blockchain technology. A private key is associated with individual nodes to link it to the owner of the account (Drescher, 2017). If the private key is lost, the owner loses access to the assets in the account (Drescher, 2017). Moreover, errors in the smart contract code can lead to leakage of data, which may make the system vulnerable to security and privacy risks (Werbach, 2018).

An increase in supply chain transparency with blockchain also has risks. With increased transparency, the exposure of the company to other actors increases, which can lead to the sharing of confidential information. Hence, there is a risk of trade secrets and supply chain details being exposed to competitors, which can give them an unfair advantage in business (Montecchi et al., 2019). To counter this problem, a private blockchain should be used where all the participants are known, and at least some are trusted.

2.2 Guidelines for Auditing

A well-defined scope is critical for conducting a good audit (BSI, 2011). This scope should include audit objectives, time and money constraints, and specific audit categories. Further, auditors should check the documentation correctly provided by the auditee. However, the specific audit categories in consideration can vary depending on the industry and the audit goals.

The set of guidelines that need to be followed to ensure that audits are conducted effectively are explained below:

1) Integrity is an important aspect of audits (British Standards Institution, 2011). Integrity can be ensured by conducting audits impartially and by complying with legal requirements.
2) The findings of the audit should be presented fairly and honestly (ISO, 2011). The auditor should ensure that any obstacle faced during the audit is reported, and an open line of communication is maintained.
3) The auditor should exercise due professional care while carrying out audits (British Standards Institution, 2011). This can be exercised by ensuring that audits are carried out according to standards.

4) The auditor should maintain confidentiality to protect sensitive information acquired during auditing (ISO, 2011). Audit information mustn't be disclosed for personal gains to ensure confidentiality.
5) The auditor should be independent to remove risks of bias and maintain objectivity (British Standards Institution, 2011). This would ensure that the audits conducted have a minimal external influence.
6) The audit should be based on samples of available information and should be verifiable (British Standards Institution, 2011). To ensure that the audit evidence is reliable and relevant, the auditor should have a clear understanding of the internal control of the company.

2.3 Chain of Custody

ISEAL Alliance (2016) defines the chain of custody as “the custodial sequence that occurs as ownership or control of the material supply is transferred from one custodian to another in the supply chain.” Chain of custody is used to track the flow of goods in a supply chain and helps in establishing traceability. On reviewing the literature, it was found that there are four chain of custody models: (i) identity preservation (ii) segregation (iii) mass balance (iv) certificate trading.

Identity preservation model: In this model, certified material is physically isolated from non-certified material and is not allowed to mix (Mol & Oosterveer, 2015). This model provides complete traceability of the product from the point of origin to the point of delivery in the supply chain.

Segregation model*:* This model allows the mixing of certified material from different certified sources (ISEAL Alliance, 2016). However, the mixing of certified material and non-certified material is not permitted in this model. Furthermore, even though the final good cannot be traced back to a single point of origin, this model assures that the final product consists only of certified materials (Mol & Oosterveer, 2015).

Mass balance model: In this model, the mixing of certified and non-certified content is permitted, provided the quantity of certified products is monitored and recorded at every stage in the supply chain. However, there is no assurance that the end-user buys certified products in this model as the mixing of certified and non-certified content is allowed (Mol & Oosterveer, 2015).

Certificate trading model: This model, also known as the book and claim model, allows certificates to be bought and applied for non-certified products (Mol & Oosterveer, 2015). Here, the final product sold with a certificate has to match the number of certified inputs. However, the certificate trading model does not establish physical traceability across the supply chain (ISEAL Alliance, 2016).

2.4 Sustainable Supply Chain Management Theory

According to Seuring & Müller (2008), the supply chain includes all processes starting from the extraction of raw materials to the final product, which encompasses both material and information flows. Over the past few years, globalization has enabled companies to source from suppliers around the world. However, with the growth of CSR, these companies have the pressure to source responsibly from suppliers.

Many factors affect sustainable supply chain management in large corporations. Provan & Skinner (1989) indicate that companies that have greater control over their suppliers can influence suppliers' decision making. According to Kim & Davis (2016), such companies will have better access to visibility across supply chains. Another factor that affects supply chain visibility is the reputation of the firm. Brooks, Highhouse, Russell, & Mohr (2003) point out that highly reputed firms are at a greater risk of losing their reputation if they do not meet the expectations of stakeholders.

The integration of social and environmental efforts with economic objectives has been suggested by Carter & Rogers (2008) to achieve sustainable supply chain management rather than solely focusing on social and environmental goals. An efficient supply chain aids in mitigating financial risks and maximizing profits in the long run (Fawcett et al., 2008). Total product life cycle and risk management are certain aspects that need to be addressed in sustainable supply chain management to identify reputational, commercial and environmental issues (Seuring & Müller, 2008).

In the context of mineral supply chains, Hofmann, Schleper, & Blome (2018) describe the concept of supply chain due diligence, which aims to manage supply chains by minimizing the use of conflict minerals. Firms that implement supply chain due diligence can benefit from improved market and financial performance (Hofmann et al., 2018). Young (2015) mentions a 'responsible sourcing' approach to aid sustainable supply chain management. This approach is used to monitor supply chains by seeking the origins of raw materials and managing upstream processes to ensure the provenance of raw materials in the supply chain (Young, 2015).

2.5 Blockchain Technology in Sustainable Supply Chain Management

The adoption of blockchain technology may be able to contribute to social sustainability in supply chains. Several researchers have suggested that digital technology like blockchain can help in enhancing traceability and provide assurance of human rights, and safe labour practices through immutable recordkeeping (Banerjee, 2018; Saberi et al., 2018).

Previous studies discuss veracity, velocity, volume, and variety as the 4V’s of big data infrastructure (Castka et al., 2020; Goes, 2014). According to Castka et al. (2020), one of the major limitations of traditional auditing practices is its lack of veracity. Blockchain technology improves veracity of data by increasing accuracy and enhances velocity by ensuring timeliness of data (Castka et al., 2020). This technology can also make it difficult for illicit goods to enter the supply chain by ensuring transparency (Apte & Petrovsky, 2016). Furthermore, by increasing the amount of data and the different types of data that can be processed, blockchain based auditing also contributes to improved volume and variety of data in comparison to traditional auditing (Castka et al., 2020).

Blockchain technology also has the potential to aid supply chain environmental sustainability. Using blockchain can make it easier to track the manufacturing process of a product and determine its footprint. For example, greenhouse gas emissions and resource consumption might be traced transparently, thereby contributing to environmental sustainability (Saberi et al., 2018).

Despite the various advantages claimed for blockchain technology, one of the major issues of using blockchain technology in sustainable supply chain management is the conversion of physical assets into a digital representation. On reviewing the literature, it was found that one way of enabling the projection of physical goods onto a digital representation is by using RFID. RFID integrated blockchain technology provides an effective way of tracking digital assets in parallel with physical assets (Tian, 2016; Toyoda et al., 2017). Through enhanced information flows, tracking of goods becomes faster and easier through a shared database.

Presently, supply chain auditing is a time-consuming process as it involves conducting on-site audits along with documentation. With blockchain technology, the time and effort needed to conduct these audits might be reduced significantly (Saberi et al., 2018). Provenance, a British startup, uses a blockchain system that relies on an RFID tag integrated with QR code to record information in the tuna supply chain (Herzberg, 2015). However, markers like RFID are limited to non-modifiable assets, which makes it impossible to track a good once it has been processed (Westerkamp et al., 2018).

To overcome this limitation, Westerkamp et al. (2018) have proposed a set of smart contracts for projecting the production process onto digital tokens. Tokens that correspond to physical goods are created within the smart contracts that can be traced back to the supply chain (Westerkamp et al., 2018). When a new smart contract is set up, the product composition is defined according to which t input materials are specified (Westerkamp et al., 2018). Specifying the required input at each stage ensures that the transaction can proceed only if each actor in the supply chain acquires a certain quantity. Using this approach, every step of the production process and raw materials used can be tracked. Hence, enabling the tokenization mechanism within the smart contract helps to resolve issues regarding discrepancies in the quantity of material.

Brink et al. (2019) suggest that for mineral supply chains, mineral volumes or weights, dates, photographs and certificates can be recorded on the ledger, which can be used to trace the materials by the various actors. The transactions can be verified by using a mass-balance approach to check if the quantity of non-certified material is controlled (Brink et al., 2019).

For establishing palm oil traceability using blockchain, Hirbli (2018) suggests an integration of geospatial imagery classification and Internet of Things (IoT) technologies using a mass balance, combined with book and claim traceability models. Hirbli (2018) asserts that by using IoT, farmers can scan the number of palm fruits harvested per day and other information such as the shipping information (Hirbli, 2018). Through real-time satellite imagery, the location of the plantation can be traced with ease using IoT and helps in knowing if deforested land has been used for the plantation. All this information may be recorded on the blockchain along with sustainable certificates, and quantities of certified and uncertified materials.

2.6 Supply Chain Attributes

This section provides an overview of the supply chain attributes, which helped in developing the framework presented in Table 4. These attributes were identified from the literature and grouped into four categories: (1) market structure; (2) product characteristics; (3) geographical scope; and (4) industry considerations. These categories were formed based on common themes found in the literature. For instance, a number of studies discuss the perishability attribute with respect to the product characteristics which has been identified as a category (Ahn & Lee, 2015; Wang & Li, 2012).

2.6.1 Market Structure

On reviewing the literature, the following four attributes were found to influence market structure: the complexity of the supply chain, product demand, time for the product to reach end-user, and value of the product.

Complexity of the supply chain: Globalization has led to an increase in outsourcing, which has increased the complexity of supply chains. According to Buhr (2003), information asymmetry due to lack of visibility across the supply chain is one of the most common issues that affect traceability. Previous studies suggest that the complexity of the supply chain is one of the main contributors of information asymmetry (Giannakis & Louis, 2011; Tachizawa & Wong, 2015).

The complexity of the supply chain is influenced by the number of tiers and actors involved in financial trade (Christopher & Lee, 2004; Mena et al., 2013; Sayogo et al., 2015). Gardner & Cooper (2003) define tiers as "the number of sequential business units performing transactions leading to the final consumer" (p.47). On reviewing the literature, it was found that the simplest form of a multi-tiered supply chain consists of three tiers (Mena et al., 2013). As the number of tiers increases, the complexity also increases, which makes it difficult for firms to manage the activities in the supply chain (Gardner & Cooper, 2003). Having a clear understanding of the number of actors involved in financial trade in a supply chain is also crucial to managing the firm's operations (Sayogo et al., 2015). The complexity increases with an increase in the number of intermediaries or traders in the supply chain.

Sayogo et al. (2015) assert that information technologies can contribute to market transparency by providing better visibility across the supply chain. This is because the integration of information using digital technology can ensure traceable information about sustainability in a timely manner (Wolf, 2011). Information technologies, therefore, support responsible sourcing in complex supply chains and help in the reduction of information asymmetry.

Product demand: The market structure is influenced by the demand for a product that is dependent on seasonal imbalances and fad volatility (Wong et al., 2005). Seasonal products are affected by fluctuating consumer demand, which can impact accurate forecasting in a supply chain (Rahman et al., 2011). Short product life cycle and high forecasting errors are some of the major challenges encountered in supply chains of such seasonal products (Kwok & Wu, 2009).

The fashion and apparel industry are seasonally driven as fashion trends move fast. This presents a challenge to retailers as they get only a short time frame to sell the product before it goes out of fashion. Kwok & Wu (2009) assert the need for improvement of supply chain visibility for accurate real-time information in the case of such seasonal products. Since declination of product value is possible with time for seasonal products, RFID and blockchain technology have been identified as solutions that could potentially improve product traceability (Burstall & Clark, 2017; Wang et al., 2016).

Time taken for product to reach end-user: Some products take a long time to pass through these different stages due to increased shipping times. Furthermore, there are instances where the delivery of the product might get delayed due to circumstances beyond control. According to Hasan et al. (2019), delays in the delivery of a shipment in the current supply chain management process can vary from several days to weeks. In these cases, the product would be temporarily stored, which leads to additional actors being introduced, increasing the risk of fraudulent practices. Previous studies have identified Radio Frequency Identification (RFID) and blockchain-based traceability systems as potential solutions to enhance visibility in such cases (Chongwatpol & Sharda, 2013; Hasan et al., 2019).

Value of the product: Farris et al. (2005) identify cost and profit as major driving factors that impact market structure. Maximizing the profits and cutting down costs is necessary for a firm to be successful. According to Russell & Hoag (2004), integrating digital technologies in supply chain management practices is expensive, making it difficult for companies to adopt it despite the benefits added by an automated traceability system. Souza Monteiro & Caswell (2004) suggest that the main motivation for private firms to invest in traceability systems is to increase profits as opposed to social welfare. This means that firms would be willing to adopt traceability systems only if high returns on the product can be ensured, and the costs can be fully recovered (Souza Monteiro & Caswell, 2004).

2.6.2 Product Characteristics

Previous studies suggest that supply chain strategies are employed in line with product characteristics, especially perishability for assuring food safety (Blackburn & Scudder, 2009). Perishability is an important attribute while evaluating the supply chains of food products that have a short shelf life. For food commodities that spoil quickly, monitoring environmental conditions, humidity, and the temperature is important to ensure quality and prevent food deterioration. Such perishable commodities can benefit from the use of traceability systems to track information in real-time. Researchers suggest the use of IoT in combination with blockchain technology to access real-time data in supply chains of perishable products (Zhang et al., 2017). IoT-connected sensors help in capturing production metrics and verifying the origin of component materials. When IoT data is fed into a blockchain, all the nodes in the supply chain can access the data (Banerjee & Venkatesh, 2019).

2.6.3 Geographical Scope

With globalization, supply chains have spread across various continents and have become more complex (Rushton, 2007). As the complexity of supply chains increases, the visibility and transparency of the supply chain decrease. It becomes difficult to track the various operations that occur across the supply chain. Merminod & Paché (2011) point out that in global supply chains, buyers focus only on first-tier suppliers, making it difficult to get a complete picture of the upstream supply chain. As the geographic scope extends from regional to international, researchers suggest the use of digital technologies like blockchain technology to reduce information asymmetry (Wang et al., 2019).

2.6.4 Industry Considerations

Previous studies suggest that supply chain performance is highly dependent on the business practices employed by the company, which is influenced by two attributes:

(i) Development culture

(ii) Risks in the industry

Development culture: According to Simonsen (1997), "development culture includes behaviours seen as desirable in employees and managers to keep organizations competitive in a rapidly changing marketplace " (p.193). The presence of a centralized governing body is a factor that affects the development culture of a firm. Digital technologies like blockchain have the potential to impact development culture by enabling peer to peer network in contrast to the traditional governing practices. The openness of an industry to innovation, is therefore important for the adoption of a digital technology like blockchain. Companies that function through bureaucratic practices tend to resist blockchain technology due to its decentralized nature (Öztürk & Yildizbaşi, 2020).

Risks in the industry: An industry that is susceptible to risks can suffer from reputational spillovers where reputations of similar firms in the same industry sector are also tarnished (Comyns & Franklin-Johnson, 2018). According to Giannakis & Papadopoulos (2016), sustainability risks include "consequences on the natural ecosystem, corporate reputation, financial exposure, as well as compliance with laws" (p.456). Kouhizadeh & Sarkis (2018) assert that risks in the upstream can be hidden due to lack of visibility, posing a major challenge for the sustainable supply chain management. To ensure ethical sourcing of raw materials, several firms are introducing supplier evaluation programs using environmental and social criteria (Kshetri, 2018).

Previous studies have highlighted the role of information technology in reducing information asymmetry and providing better visibility of the supply chain (Ramaswamy, 2017). By digitizing interactions among various business processes, information technology has the potential to reduce fraudulent practices, thereby mitigating risks.

2.7 Initiatives Towards Improving Traceability

This section gives an overview of some of the notable initiatives to promote responsible sourcing in three different industries: conflict minerals, fisheries, and the automobile industry.

2.7.1 Conflict Minerals

Conflict minerals, tin, tantalum, tungsten and gold, commonly known as the 3TG minerals originate from the eastern Democratic Republic of Congo (DRC) where human rights abuses and violence have been used to finance illegal mining activities. Monitoring the origins of these conflict minerals is difficult due to the globalization of supply chains. Due to the widespread use of conflict minerals in the electronics industry, concerns have been raised by NGOs and in the media to address the issue of sourcing these minerals from conflict-prone areas.

As a result of this social concern, various efforts have been taken to ensure responsible sourcing in mineral supply chains. Section 1502 of the Dodd-Frank Act passed by the United States in 2010 was aimed at stopping finance for armed groups by making it mandatory for companies to report on 3TG metal use. In 2017, the European Union passed Regulation 2017/821, which specifies the supply chain due to diligence obligations for conflict minerals (European Commission, 2018). The Organization for Economic Co-operation and Development Due Diligence Guidance provides a framework for responsible sourcing of 3TG minerals (OECD, 2016).

The Responsible Minerals Initiative (RMI) is another prominent effort to address responsible sourcing of mineral supply chains. This initiative considers smelters and refiners as "chokepoints" (Young, 2018). These chokepoints are targeted to provide assurances on the sustainability of minerals (Young, 2015). The chain of custody that tracks the flow of minerals from mine to export is thereby monitored by targeting these chokepoints. This is presented in Figure 2. The RMI has also recently drafted Blockchain Guidelines to facilitate the usage of common definitions in the application of blockchain solutions in minerals supply chain due diligence (RMI, 2020). These guidelines help in establishing consensus on data attributes for using blockchain in mineral supply chains. Another notable initiative in the case of mineral supply chains is the project launched by Peer Ledger, which uses blockchain to ensure responsible sourcing of gold (Peer Ledger, 2020).

The International Tin Industry Association is a non-profit organization that promotes conflict-free sourcing of tin globally. An in-region program called the International Tin Industry Association Tin Supply Chain Initiative provides traceability of tin and ensures responsible sourcing (ITRI, 2013; Young & Dias, 2011). This program uses a bag-and-tag scheme to promote due diligence and establish traceability (Hogg, 2012).

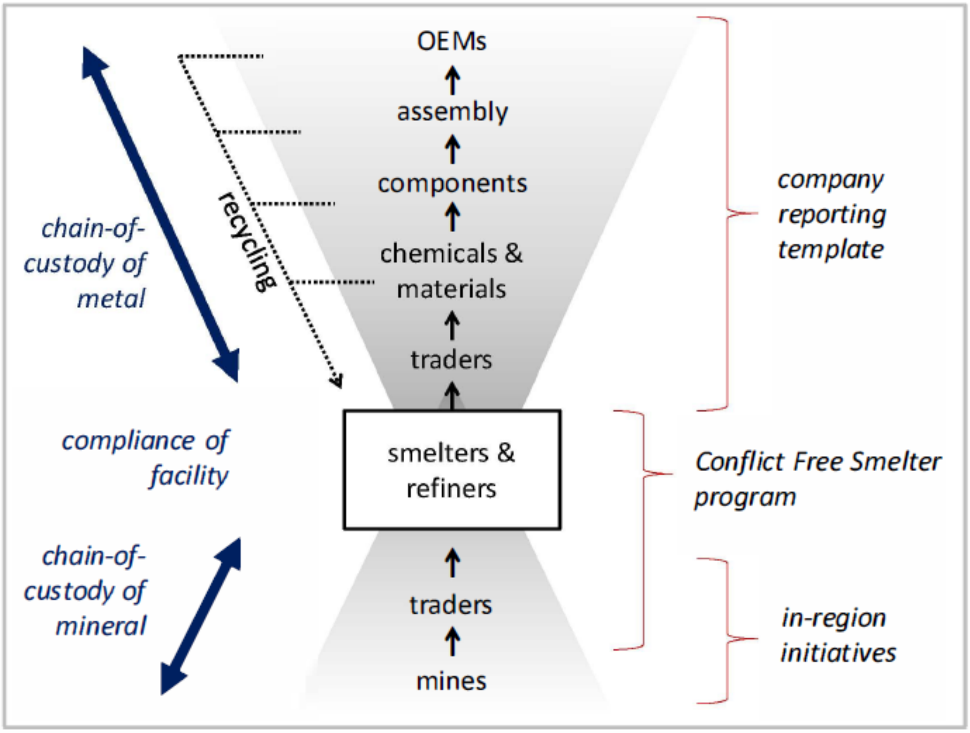

Figure 2 : Product chain of conflict minerals. Adapted from 'Conflict-free minerals supply-chain to electronics' by Young & Dias, 2012

2.7.2 Fisheries

The global seafood industry faces criticism due to illegal, unreported, and unregulated activities, which includes overfishing and human rights violations (Cook & Zealand, 2018). Quality improvement, recall cost reduction and management improvement are the common drivers for implementing a traceability system in the fisheries sector (Wang et al., 2009). Introducing an electronic-based traceability system can reduce information asymmetry and provide quality assurance to consumers (Hobbs, 2003). Additionally, electronic-based traceability systems reduce labour costs and human effort compared to paper-based systems (Alfaro & Rábade, 2009).

There have been various steps taken to ensure sustainable fishing. The Marine Stewardship Council is one of the leading sustainability certifications in the fisheries sector. The Marine

Stewardship Council standard is based on three principles. Every fishery needs to consider the condition of the target fish stock, the impact of the fishery on the ecosystem, and the performance of the fisheries management system (Ward & Phillips, 2010). The Lacey Act passed in the year 1900 and later amended in 2008 promotes sustainable fishing practices by prohibiting the trade of illegally harvested fish in the United States (Kashmanian & Moore, 2014).

2.7.3 Automotive Industry

Car manufacturing companies are taking corporate sustainability into account while redefining business objectives to mitigate social and environmental concerns (Sukitsch et al., 2015). According to the International Energy Agency, the transport sector contributes to twenty-two percent of the global greenhouse gas emissions (Tanaka, 2010). In a study carried out by the Capegemini Research Institute (2018), it was found that sustainability has become a strategic priority in the automotive industry to satisfy consumer expectations.

Drive Sustainability is a collaboration of ten automotive manufacturing companies to promote sustainability in the automotive industry (Drive Sustainability, 2018). The Drive Sustainability partnership fosters the integration of sustainability into the purchasing of materials in the automotive industry. The Material Change report by Drive Sustainability gives a summary of the materials important to the automotive industry and the association of these materials with environmental, social and governance (ESG) issues (Drive Sustainability, 2018). This report is public and provides a broad comparative industry-level assessment of upstream risks. The Material Change report is also unique because it provides a comparison across dissimilar commodities. Appendix A shows the ratings of the materials consumed in the automotive industry against their association with ESG issues.

Chapter 3: Methods

This chapter explains the methods used for this research to develop and use a tool for assessing the suitability of blockchain technology for responsible sourcing in commodity supply chains. The framework used for the analysis and the steps taken for developing the decision tree tool are elaborated. Additionally, the decision tree tool that was developed is also presented in this chapter.

3.1 Research Approach

The research used a qualitative approach, drawing on data from experts, academic literature, industry reports and media reports. For six commodities (oranges, fish, cotton, palm oil, cobalt, and tin), experts where the primary source of information. For these commodities, data triangulation was carried out by validating the findings from academic literature, industry reports and media reports with experts. For the additional commodities (cocoa, coffee, rubber, aluminum, diamonds, and mica), experts were not available for data collection. Secondary data from academic literature, industry reports and media reports were the source of data for these commodities.

The scope of this research is global, with the upstream supply chain being the unit of analysis. The commodity supply chains included complex international trade, with multiple tiers spanning across different countries due to the global nature of the commodity supply chains that are evaluated. The temporal scope is defined by current market and supply chain practices. A ten-year time window (2010 to 2020) was used in this research to assess several of the attributes visible in commodity supply chains (e.g., presence of sustainability risk).

The experts consulted were industry professionals with several years of experience and extensive knowledge about the commodity supply chains. They were identified via business connections to the Responsible Minerals Initiative and via academic colleagues working on sustainability of mining, minerals, agriculture and food. These experts were qualified in different ways; all offered detailed expertise on one or more commodities. Some of these experts were professional auditors who had experience working in multiple supply chains. All the experts who were consulted had several years of experience working in a specific supply chain and had working knowledge of the sustainability risks in that industry.

A total of six experts were consulted between December 2019 and March 2020 to triangulate the findings from the academic literature, industry reports and media reports and to assess the veracity of the decision tree for a particular commodity. Three of the six experts were consulted over a dial-in conference call system using the Zoom platform and the other three experts were met in-person. The experts reviewed the research findings and tested the decision tree over a period of forty-five to sixty minutes. The completeness of the decision criteria and the utility of the decision tree for each commodity were captured by detailed notes taken during each consultation. These notes were then referred to assess the commodity supply chains using the assessment tool which has been explained in Section 3.2.1 and Section 3.2.2.

Documents consulted were academic literature, industry reports and media reports. These were analysed using simple methods to identify and confirm the presence of attributes in commodity supply chains. For some attributes (e.g, trust, presence of digital technology to monitor risks, and openness to innovation), coding was performed using a "presence of" basis. This was a simple binary approach, requiring no counting or additional quantification where measures were either present or not (which could be interpreted as a one or zero code). In other areas, like identification of risks, more detailed assessment was performed that enable comparison across the twelve commodities. Results for these attributes were recorded as either “Yes” or “No”.

3.2 Development of the Assessment Tool

The development and testing of the assessment tool used in this research were carried out in two phases:

(i) Development of a rubric

(ii) Development of a decision tree

These two phases are elaborated in Section 3.2.1 and Section 3.2.2.

3.2.1 Development of Rubric

In this phase, a comprehensive literature review was conducted on blockchain technology and sustainable supply chain management by studying academic literature and grey literature. Academic literature was reviewed for understanding the critical properties of blockchain and the consensus mechanisms. A search on startup firms that are using blockchain technology for sustainable supply chain management was performed on Google to identify relevant grey literature consisting of whitepapers. These whitepapers were then studied to understand the different use cases of blockchain technology in supply chain management. This was followed by discussions with experts in auditing and certifications to understand the various factors that impact sustainable supply chain management.

From the literature review and industry studies, a rubric was developed as a tool to evaluate the use of blockchain technology in various industries for ensuring responsible sourcing. A rubric is a scoring tool that uses criteria for rating important dimensions of performance in the area of interest (Jonsson & Svingby, 2007). These dimensions of performance are rated using numerical scores, which helps in the assessment of outcomes.

The initial phase of development of the rubric listed attributes that are significant to the supply chain. Eight attributes were identified from the literature review, which were organized into categories according to the market structure, product characteristics, geographical scope, and industry considerations (see Section 2.6). The rubric helped in identifying attributes of the supply chain that may have a significant impact on the use of blockchain technology. Each category in the rubric (see Table 1) was given a certain weightage depending on its relevance to blockchain. Threshold values were assigned for each of these attributes and a 'blockchain feasibility score' was set corresponding to the threshold values. The blockchain feasibility scores were then normalized and converted to a scale of one to ten with one being least favorable for blockchain and ten being most favorable for blockchain. The commodity supply chains were then evaluated to obtain a 'commodity evaluation score' for each attribute. The commodity evaluation scores were then multiplied with the category weightage and the average was taken to find the blockchain suitability rating. The initial draft of the rubric is shown in Table 1.

Table 1: Rubric to assess attributes of commodity supply chains

Category	Attributes	Threshold value	Blockchain feasibility score	Normalized blockchain feasibility score (range: 1-10)	Commodity evaluation score
Market structure	Complexity of the supply chain				
	Commodity demand				
	Value of commodity				
	Time to end-user				
Product characteristics	Perishability				
Geographical scope	Movement of the commodity through the supply chain				
Industry considerations	Development culture				
	Sustainability risks				

This rubric was then used to assess if blockchain was a suitable solution for addressing the sustainability issues in the orange industry. The orange industry was chosen as the first test case as the expert was conveniently located. Further, oranges align with the scope of the study since they are global commodities. Oranges were also perceived to have fewer sustainability risks in comparison to the other commodities which made it easier to test the rubric for oranges. While testing the rubric, it was found that the rubric might not be an appropriate tool to assess the feasibility of blockchain solutions. It was found that attributes like trust between actors in the supply chain that could have a significant impact on the use of blockchain technology were missing from the rubric. Additionally, there was difficulty in quantifying some attributes in the rubric. It was understood that there was an overlap between specific attributes which meant that assigning numerical values to them could result in double counting and make the results inaccurate. For instance, attributes like ‘movement of the commodity through the supply chain’ and ‘time to reach end-user’ were closely related. Generally, when the commodity travels a larger distance and crosses national borders, the time taken for the commodity to reach the end-user also increases. This led to the conclusion that a more practical tool was needed to test the suitability of blockchain solutions for responsible sourcing in supply chains.

3.2.2 Development of Decision Tree

After testing the rubric, a decision tree was developed to test the practicality of using blockchain in sustainable supply chain management. A decision tree aids in the decision-making process by classifying attributes. At every node in the decision tree, an attribute is assessed, and the output of the test is represented at the branch of the tree. Following a top to bottom approach, an important attribute that has a higher priority in determining the outcome is placed at a higher layer of the decision tree. The process of classifying the data continues until some stopping condition is met, leading to the outcome of the decision tree. A decision tree was used for this study because it is simple to understand, and its applicability can be extended to a wide range of commodities.

The attributes of the supply chain used to build the rubric in the first phase served as the basis for framing the questions of the decision tree. Various studies in the past have identified trust between the actors as a crucial factor that can affect the adoption of blockchain technology (Hawlitschek et al., 2018; Werbach, 2018). The presence of existing digital technology to monitor sustainability risks could also potentially impact the adoption of a nascent technology like blockchain. Therefore, in addition to the attributes presented in Section 3.2.1, attributes such as trust between actors in the supply chain and the presence of digital technology to monitor risks in the supply chains were also included in the decision tree.

These attributes were then listed and then ranked in the order of their priority according to their relevance to blockchain to form the decision tree. The questions in the decision tree were placed in such a way that the supply chain attributes which directly influence the use of blockchain technology come at the top of the tree.

To assess the questions in the decision tree, it is important to set criteria or thresholds against which the commodity supply chains can be evaluated. Since all the assessed supply chains in this research are global in scope, it is assumed that they typically consist of at least three tiers. Hence, any supply chain having more than three tiers was deemed complex because evidence from the literature shows that the simplest multi-tier supply chain consists of three tiers (Mena et al., 2013). For other attributes like value of the commodity and time taken to reach the end-user, specific cut-offs were established. For example, one month was established as the cut-off for time taken by commodity to reach end-user. This means that that any commodity that takes more than one month to reach the end-user can be assumed to take a long time to travel through the supply chain. Similarly, ten dollars was established as the cut-off for assessing the value of the commodity. This means that any commodity with a wholesale price of ten dollars per kilogram or higher was categorized as high-value commodity for the purpose of this study. Table 2 presents results of price of the twelve commodities chosen for this research. In most cases, the commodity exchange price was used for assessing the value of a commodity. For mica, the world market price was used as mica it is not an openly traded commodity. Fish pricing was more complex, as it comprises many species and grades, with the price of fish varying significantly. For the purposes of the current study shrimp was chosen as a representative (see Table 2).

Table 2: Price of commodity

Commodity	Price ($/ kg)	References
Cocoa	$2.25	NASDAQ. (2020, March 25). https://www.nasdaq.com/market-activity/commodities/cj%3anmx
Coffee	$2.87	NASDAQ. (2020, March 25). https://www.nasdaq.com/market-activity/commodities/kt%3anmx
Rubber	$1.5	Singapore Commodity Exchange. (2020, March 25). https://www.indexmundi.com/commodities/?commodity=rubber&months=300
Aluminum	$1.5	London Metal Exchange. (2020, March 25) https://www.lme.com/Metals/Non-ferrous/Aluminium#tabIndex=2
Diamond	$27,000,000-155,000,000 (approximately)	International Diamond Exchange. (2020, March 25). http://www.idexonline.com/diamond_prices_index
Mica	$1000-2000 (approximately)	Wired Magazine. (2015). https://www.wired.co.uk/article/mica-illegal-mining-india
Fish (shrimp)	$20.32	NOAA Fisheries, (2016, March 17). https://fish.nefsc.noaa.gov/read/socialsci/dataPicker.php
Oranges	$2.58	Intercontinental Exchange Futures U.S. (2020, March 25) https://www.theice.com/products/30/FCOJ-A-Futures/data?marketId=5578838&span=1
Cotton	$1.18	NASDAQ. (2020, March 25). https://www.nasdaq.com/market-activity/commodities/tt%3anmx
Palm Oil	$0.57	Bursa Malaysia Exchange. (2020, March 25). https://markets.businessinsider.com/commodities/palm-oil-price
Cobalt	$29.5	London Metal Exchange. (2020, March 25). https://www.lme.com/en-GB/Metals/Minor-metals/Cobalt#tabIndex=2
Tin	$13.72	London Metal Exchange. (2020, March 25). https://www.lme.com/en-GB/Metals/Non-ferrous/Tin#tabIndex=2

For the purpose of this study, sustainability risks are defined as ESG issues that may trigger harmful stakeholder reactions and affect the reputation of the downstream company. In this study, sustainability risks were classified into five types: environmental, health and safety, human rights, conflict and governance. For each of these risks, certain keywords were used as shown in Table 3.

As mentioned in Section 3.1, international media reports from 2010 to 2020 were used for the assessment of sustainability risks. This period was used as the time frame for the analysis assuming that risks that have received international media attention in this period of ten years would still be relevant. For evaluating the significance of sustainability risks, the research looked for whether there were at least three international media sources mentioning a particular risk area (e.g., “child labour”). It was judged that one media source was inadequate, as it may have been an outlier, perhaps politically or otherwise biased, whereas at least three independent sources, present in international media, was judged to be of significant evidence. Further, this criterion was chosen because it provided consistent assessment of sustainability risks across all the commodity supply chains.

For locating relevant news reports, Google News was used as the search engine and only news reports in English were considered. Google News was selected for searching media reports because it is easy to use and offers news coverage aggregated from sources all over the world. From the search results, credible reports mentioned in reputed international media sources were used for the final analysis. Reputability of sources was measured based on the rating of factual accuracy and political bias on Media Bias/Fact Check (Media Bias/Fact Check, n.d.). Media sources with ‘low’ and ‘very low’ ratings of factual accuracy were excluded from the analysis. In addition to media reports, the Drive Sustainability (2018) report was also used to assess the ESG risks associated with certain commodities like aluminum, cobalt, tin and mica. For assessing the sustainability risks for specific commodity supply chains, the AND function was used to pair the keywords with each of the following; “cocoa”, “coffee”, “fish”, “oranges”, “cotton”, “palm oil”, “rubber”, “aluminum”, “cobalt”, “tin”, “diamonds”, and “mica”.

To assess the other attributes (trust, presence of digital technology to monitor risk, and openness to innovation for commodity supply chains), where experts were not available, a keyword search was conducted using Google Scholar to locate relevant sources of data (see Table 3). Google Scholar was used as the search engine for these attributes because it collates scholarly documents and is free to use. In this study, presence of digital technology is assessed by searching the academic literature for mentions of digital tracking software other than blockchain which includes RFID, IoT or other mobile applications. Openness to innovation is assessed based on the efforts and initiatives taken by the industry (e.g. RMI) to ensure responsible sourcing using blockchain technology to track the commodity’s supply chain.

Table 3: Keyword search in Google News and Google Scholar

Attributes		Keywords	Search engine	Source of Data
Trust between actors		"bribery", "fraud", "scandal"	Google Scholar	Academic literature and industry reports
Presence of digital technology		“RFID”, “IoT”, “mobile applications”, “digital technology”	Google Scholar	Academic literature
Openness to innovation		“industry initiatives”, “blockchain pilot”, “technology infrastructure”	Google Scholar and Google News	Academic literature and media reports
Sustainability Risks	Environmental	"deforestation", "biodiversity", "environmental degradation"	Google News	Media reports and industry reports
	Health & Safety	"health and safety", "EHS"		
	Human Rights	"child labour", "forced labour", "human rights abuses"		
	Conflict	"armed conflict", "conflict mineral"		
	Governance	"corruption", "illegal", “unregulated”		

3.3 Decision Tree

After development of the elements in the decision tree, it was necessary to organize the questions into a tree structure. A logical sequence was formulated based on the relevance of blockchain technology to the identified supply chain attributes. The key properties of blockchain (i.e. transparency, immutability, decentralization, and integrity) helped in formulating this sequence as described below.

One of the underlying principles of blockchain is its ability to build trust. Blockchain ensures integrity and transparency of data which helps in building trust between various actors. If trust already exists between various actors in the supply chain, blockchain technology will not add much value. Several studies have identified trust as an important factor that could affect the adoption of blockchain (Hawlitschek et al., 2018; Werbach, 2018). This forms the basis for the first question:

Q.1: Is there trust between actors in the supply chain?

Decentralization, which is one of the key properties of blockchain, can ensure that the information related to the commodity's supply chain is visible equally and simultaneously to multiple stakeholders. The blockchain system can alert relevant stakeholders if there are sustainability concerns and thereby mitigate sustainability risks (environmental risks, health and safety risks, human rights risks, conflict risks, and governance risks). If there are no significant sustainability risks in the industry, investing in a sophisticated technology like blockchain may not be necessary. This leads to the second question:

Q.2: Are there significant sustainability risks in the supply chain?

A commodity supply chain with high levels of complexity can be difficult to track and can benefit from digital technology like blockchain. The decentralized form of governance in a blockchain can ensure that audit trails can be tracked with ease. However, if the supply chain is not complex, it may be practical to use a low-cost technology in comparison to the blockchain. From the literature review, it was understood that the simplest form of a multi-tiered supply chain consists of three tiers (Mena et al., 2013). Hence, any supply chain having more than three tiers was deemed complex. Therefore, the third question is:

Q.3: Is the commodity supply chain complex?

If the commodity supply chain is complex, it becomes important to evaluate if the supply chain is contained within a single geographical location or spread over wider areas. Transparency, being one of the key properties of blockchain technology, can be useful to track the flow of the good when the commodity supply chain is not confined to a single region. This forms the basis for the fourth question in the decision tree:

Q.4: Does the commodity cross national borders?

Blockchain, combined with existing technologies like IoT, can provide solutions to effectively track commodities in real-time (Zhang et al., 2017). Perishable commodities that are prone to spoilage require constant monitoring of temperature and humidity, which can be done using blockchain. Hence, the fifth question of the decision tree is:

Q.5: Is the commodity perishable?

The next attribute that needs to be evaluated is the fluctuation in the demand of the commodity. It is important to have a robust tracking system for seasonal commodities as delays in delivery can lead to economic losses due to the short time frame available for selling them. Such commodities can benefit from the use of blockchain, which leads to the sixth question of the decision tree:

Q.6: Is the commodity demand uninfluenced by seasonal variations?

The time taken for a commodity to reach the end-user is another attribute that needs to be evaluated. If the commodity takes a long time to reach the end-user, an automated information tracking system like blockchain can be used to record transactions to increase the visibility of the supply chain. This leads to the seventh question of the decision tree:

Q.7: Does the commodity take greater than one month to reach the end-user?

If technology like a blockchain needs to be introduced in sustainable supply chain management, it is important that the value of the commodity is high. However, even if the value of the commodity might be low, a blockchain solution might still be practical depending on the severity of the risk involved and the need for visibility in the supply chain. This leads to the eighth question in the decision tree:

Q.8: Is the value of the commodity greater than ten dollars per kilogram?

It is important to assess if there is a digital technology-based traceability system to monitor the risks in the supply chain. If digital technology already exists to provide visibility of the activities in the supply chain, then a blockchain solution can be deemed impractical. This leads to the ninth question in the decision tree:

Q.9: Is there digital technology in place to monitor sustainability risks?

For a technology to be used effectively in any industry, the industry should be open to technological advancements. If the commodity is high value and the industry is resistant to technological innovations, this poses a challenge for the successful implementation of blockchain. However, blockchain is desirable in this case and is a feasible solution if the challenges are addressed. This leads to the tenth question in the decision tree:

Q.10: Is the industry open to technological innovation?

The framework for analyzing the supply chain attributes relevant to blockchain technology is presented in Table 4.

Table 4: Framework for analyzing supply chain attributes relevant to blockchain technology

Category	Attribute	Question	Criteria
Market structure	Complexity of the supply chain	Is the supply chain complex?	**Yes**- Commodity supply chain consists of more than three tiers **No**- Commodity supply chain consists of three tiers or less
	Fluctuations in commodity demand	Is the commodity demand uninfluenced by seasonal variations?	**Yes**- Commodity is in demand throughout the year **No**- Commodity is seasonal and in demand during certain periods in a year
	Duration of commodity in the supply chain	Does the commodity take a long time to reach the end-user?	**Yes**- Commodity takes one month or greater to reach the end-user from the time of production **No**- Commodity takes less than one month to reach the end-user from the time of production
	Value of the commodity	Is the value of the commodity high?	**Yes**- Commodity has a value of ten dollars per kilogram or higher **No**- Commodity has a value of less than ten dollars per kilogram
Product characteristics	Perishability	Is the commodity perishable?	**Yes**- Commodity is prone to spoilage if temperature or humidity conditions are not maintained. **No**- Commodity is not prone to spoilage and does not require monitoring of temperature or humidity
Geographical scope	Movement of commodity through the supply chain	Does the commodity cross national borders?	**Yes**- Commodity moves across different countries **No**- Commodity supply chain is confined to the same region
Industry considerations	Risks to buyer	Are there significant sustainability risks?	**Yes**- Sustainability risks from 2010 to 2020 that have been mentioned in at least three international media reports **No-** Sustainability risks from 2010 to 2020 that have not been mentioned in at least three international media reports
	Trust between actors	Is there trust between actors in the supply chain?	**Yes-** Presence of bribery or fraud in academic literature or industry reports **No**- Lack of presence of bribery or fraud in academic literature or industry reports
	Presence of digital technology to mitigate risks	Is there digital technology in place to monitor risks in the supply chain?	**Yes** – Presence of RFID, IoT, mobile applications or digital tracking software other than blockchain **No**- Lack of presence of RFID, IoT, mobile applications or other digital tracking software
	Development culture	Is the industry open to innovation?	**Yes-** Presence of initiatives taken by the industry promoting the use of blockchain **No**- Lack of presence of initiatives taken by the industry promoting the use of blockchain

Subsequently, the decision tree was developed (Figure 3). Broadly, the decision tree was used for biotic and abiotic commodity supply chains. Using the decision tree, different categories of commodities such as food, non-food, metals and non-metals were assessed to evaluate if there were any trends or patterns in the results of the chosen commodities. Prior to using the decision tree, the experts were asked questions to clarify the context of discussion, which can be found in Appendix B. The questions in the decision tree are Yes or No questions and further probing questions were asked depending on the answer given by the expert to get more details. These probing questions were framed around the keywords presented in Table 3. For example, in the case of attributes like openness to innovation, questions around industry initiatives and blockchain pilot projects were asked as follow-up questions depending on the answer given by the expert.

The decision tree leads to four possible outcomes: (i) do not use blockchain, (ii) might need blockchain depending on the severity of the risks involved, (iii) blockchain is desirable, but some challenges need to be addressed, and (iv) use blockchain. The initial draft of the decision tree was then assessed using the case of fishery supply chains, which led to the conclusion that blockchain was desirable for managing supply chains in the fishing industry provided challenges are addressed. Fisheries being a global supply chain was chosen as the first test case of the decision tree due to the significant risks associated with the fisheries sector. Evaluating the initial draft of the decision tree for fisheries also helped refine the design of the decision tree. It was understood that Question 8 ('Is the value of the commodity greater than ten dollars per kilogram?') had to be placed at a higher layer of the decision tree as it had greater significance in determining the outcome in comparison to Question 9 ('Is there digital technology in place to monitor sustainability risks?'). After rectifying these gaps by reordering the decision tree, the final draft of the decision tree tool was developed (Figure 3).

3.4 Limitations

A major limitation of the methods in this study is the choice of specific criteria that were used to assess certain attributes in this study. Complexity of the supply chain is the only attribute for which the criteria was based on evidence from the literature. The criteria used for all the other attributes were based on specific cut-offs, which were ad hoc but were considered in consultation with the expert. For example, ten dollars was established as the cut-off for assessing the value of a commodity as high or low. Similarly, a value of one month was set as the threshold for evaluating the time taken for the commodity to reach the end-user. The findings of this study are based on these thresholds and the outcome of the decision tree could change if a different cut-off was used for assessing the attributes.

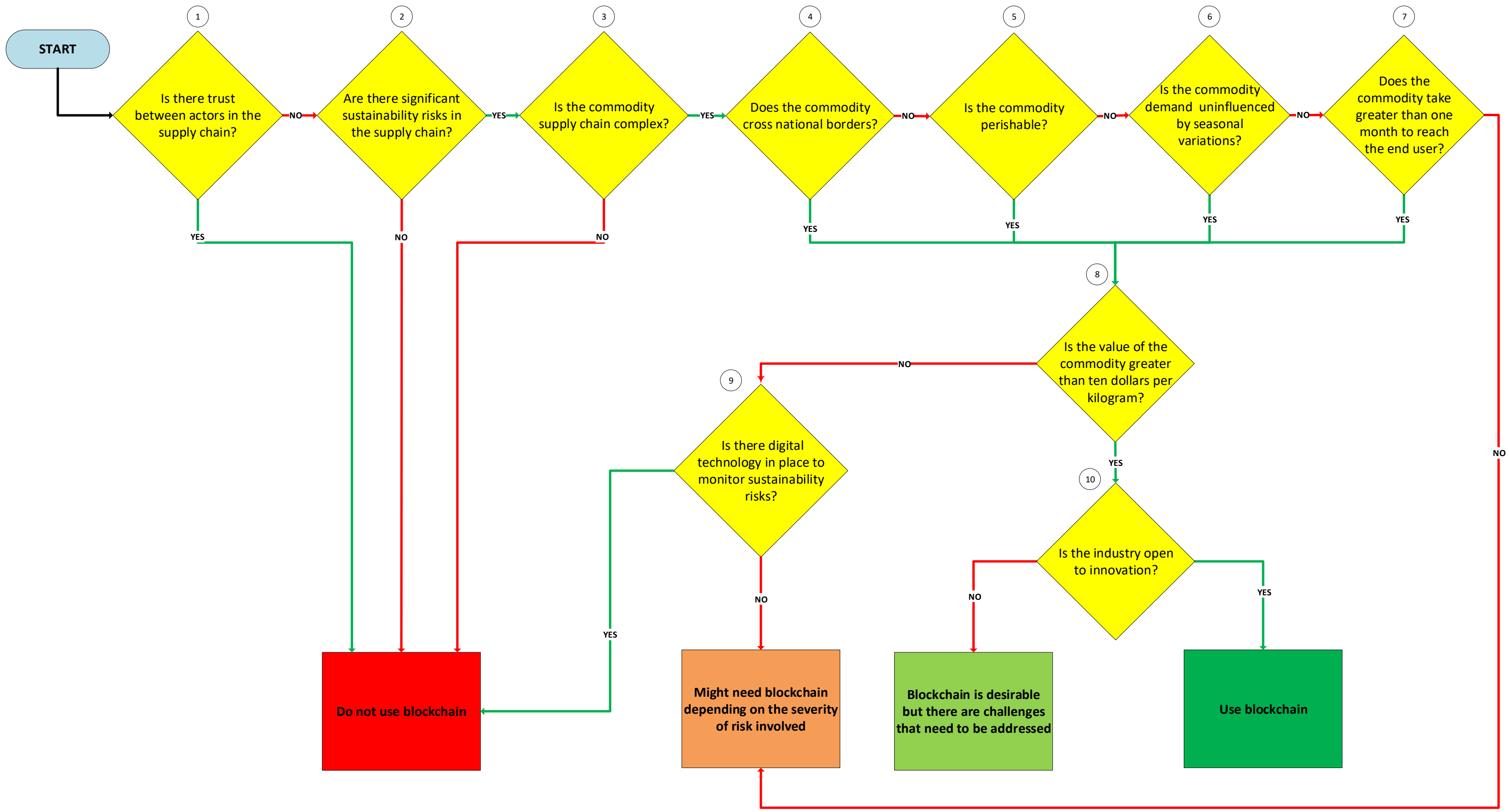

Figure 3: Decision tree for assessment of commodity supply chains on suitability of blockchain technology for responsible sourcing

Chapter 4: Results

This chapter presents the results of the decision tree analysis for the twelve commodity supply chains that were assessed.

Table 5 presents the summarized results for all commodites across all the questions in the decision tree. These outcomes are based on the detailed results that are summarized below for each commodity. The results obtained in this chapter present an opportunity to identify the trends and patterns in these commodities. Furthermore, the results contribute to a better understanding of the attributes associated with a commodity's supply chain that may make it suitable for using blockchain technology. The sustainability risks associated with the assessed commodities are also summarized in this chapter.

4.1 Decision Tree Outcomes

Several attributes appeared to be consistent across the supply chains: trust, risks and complexity. A lack of trust among actors was observed in all the assessed commodity supply chains. All the commodity supply chains evaluated also had significant sustainability risks associated with them, except for the orange industry, where environmental issues and social problems have not received international media attention. Further, since the scope of this research is global, all the assessed commodity supply chains are complex with several sub-suppliers and consists of more than three tiers. The decision tree for cocoa has been traced in Figure 4.

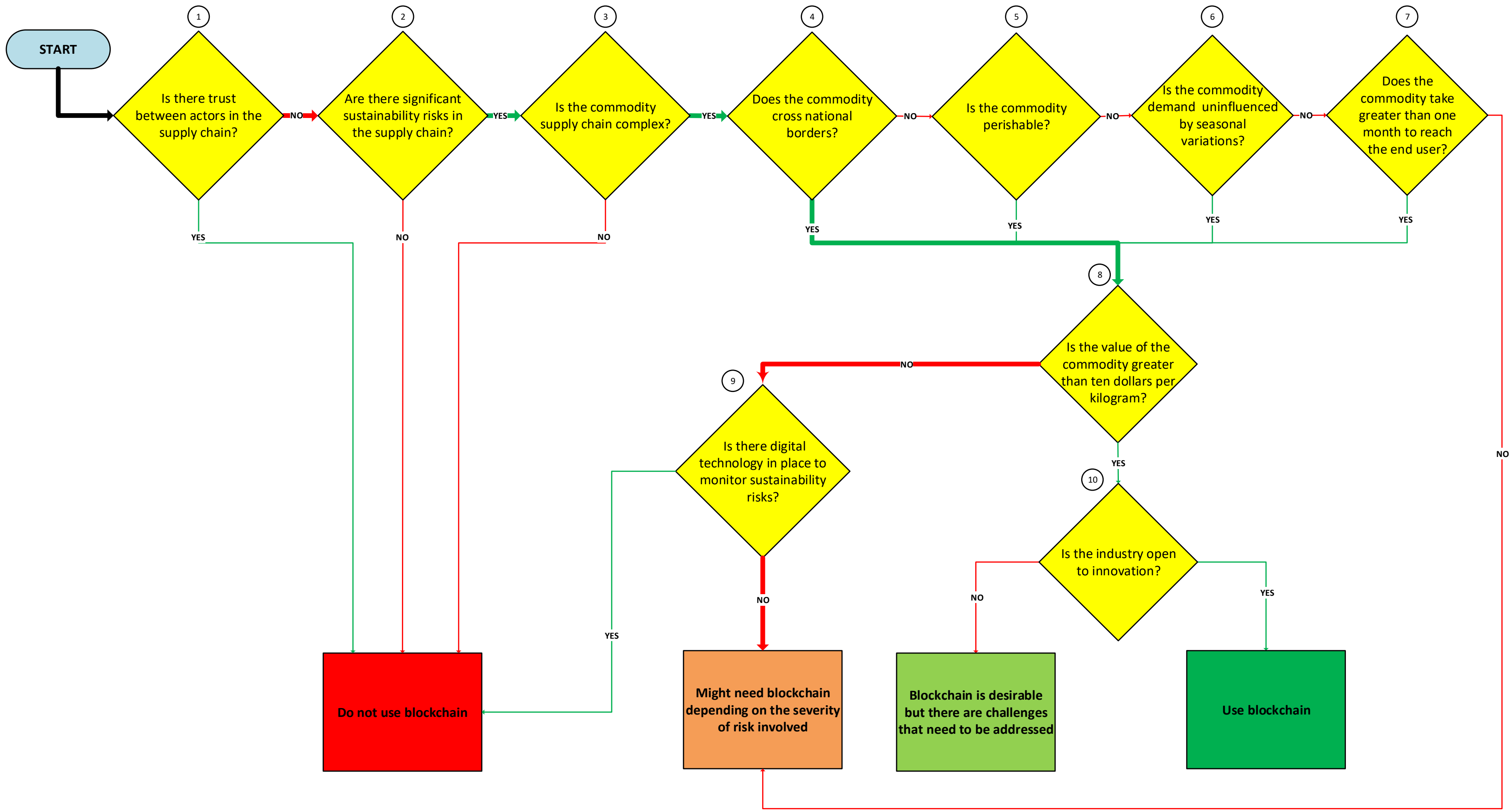

Figure 4: Decision tree for cocoa

Among the evaluated food commodities, only fish (shrimp) was assessed as being of high value, while the other commodities like cocoa, coffee and oranges were found to be of low value (less than ten dollars per kilogram). All the non-food biotic commodities tested (cotton, rubber, and palm oil) were of low value. In contrast, metals and non-metals that were evaluated were high value, with the exception of aluminum, which was classified as a low-value commodity.

The experts identified lack of openness to innovation as a major barrier to incorporating blockchain for certain high-value commodities like fish, tin, and mica. In these industries, even though blockchain was desirable, the industry was not progressive towards adopting innovative technology like blockchain. This was based on the absence of pilot projects or industry initiatives to promote responsible sourcing using technology in these industries. One reason for this lack of openness to innovation mentioned by experts was the absence of technology infrastructure to support a solution like blockchain in the upstream especially in developing countries. The experts, however, identified the cobalt and diamond industry to be progressive with respect to accepting new technologies and being open to innovation, which implies that these industries could use blockchain, making it a feasible solution.

On evaluating the low-value commodities further, it was found that there were no digital technology systems in place to monitor the supply chain risks in most supply chains. Palm oil was one exception: the ULULA platform was identified as a tool that can provide transparency and address the risks in the palm oil industry (RSPO, 2018). Hence, on testing the decision tree, it was found that blockchain was not a feasible solution for palm oil. There were no existing digital technologies identified to ensure responsible sourcing for the other low-value commodities tested, which included cocoa, coffee, oranges, cotton, rubber and aluminum as shown in Figure 4. According to the decision tree, blockchain may be viable for these commodities depending on the severity of the risk involved and the reputation of the downstream brand. The summarized results of the decision tree for the twelve tested commodity supply chains are shown in Table 5 below.

Table 5: Summarized results of the decision-tree analysis for each commodity

Legend	
✓	**Yes**
×	**No**

Commodity			**Question**										**Outcome**
			Is there trust between actors in the supply chain?	Are there significant sustainability risks in the supply chain?	Is the supply chain complex?	Does the commodity cross national borders?	Is the commodity perishable?	Is the commodity demand uninfluenced by seasonal variations?	Does the commodity take greater than one month to reach the end-user?	Is the value of the commodity greater than ten dollars per kilogram?	Is there digital technology in place to monitor risks?	Is the industry open to innovation?	
Biotic	Food	Cocoa	×	✓	✓	✓	✓	✓	×	×	×	✓	[orange]
		Coffee	×	✓	✓	✓	✓	✓	✓	×	×	✓	[orange]
		Fish	×	✓	✓	✓	✓	✓	(1)	✓	✓	×	[light green]
		Oranges	×	×	✓	✓	✓	✓	×	×	×	×	[red]
	Non-food	Cotton	×	✓	✓	✓	×	✓	×	×	×	✓	[orange]
		Palm oil	×	✓	✓	✓	✓	✓	×	×	✓	×	[red]
		Rubber	×	✓	✓	✓	×	✓	×	×	×	×	[orange]
Abiotic	Metals	Aluminum	×	✓	✓	✓	×	✓	✓	×	×	✓	[orange]
		Cobalt	×	✓	✓	✓	×	✓	✓	✓	×	✓	[green]
		Tin	×	✓	✓	✓	×	✓	✓	✓	×	×	[light green]
	Non-metals	Diamond	×	✓	✓	✓	×	✓	✓	✓	×	✓	[green]
		Mica	×	✓	✓	✓	×	✓	✓	✓	×	×	[light green]

(1) Varies; Fish takes a short time to reach the end consumer except in the case of frozen fish which can take several months to travel through the supply chain

Color	**Outcome**
[red]	Do not use blockchain
[orange]	Might need blockchain depending on the severity of risk involved and the need for visibility
[light green]	Blockchain is desirable but there are challenges that needs to be addressed
[green]	Use Blockchain

4.2 Commodity Profiles

This section gives a summary of each of the commodities. The summarized results of significant sustainability risks identified for the assessed commodity supply chains are presented in Table 6.

Table 6: Significance of sustainability risks identified in twelve commodity supply-chains

Type	Category	Commodity	Risks				
			Environmental	Health & Safety	Human Rights	Conflict	Governance
Biotic	Food	Cocoa	Significant	Not Significant	Significant	Not Significant	Not Significant
		Coffee	Significant	Not Significant	Significant	Not Significant	Not Significant
		Fish	Significant	Not Significant	Significant	Not Significant	Significant
		Oranges	Not Significant	Not Significant	Not Significant	Not Significant	Not Significant
	Non-food	Cotton	Significant	Not Significant	Significant	Not Significant	Not Significant
		Palm oil	Significant	Significant	Significant	Not Significant	Not Significant
		Rubber	Significant	Not Significant	Significant	Not Significant	Not Significant
Abiotic	Metals	Aluminum	Significant	Significant	Not Significant	Not Significant	Significant
		Cobalt	Not Significant	Significant	Significant	Not Significant	Significant
		Tin	Significant	Significant	Significant	Significant	Not Significant
	Non metals	Diamonds	Not Significant	Significant	Significant	Significant	Not Significant
		Mica	Not Significant	Significant	Significant	Not Significant	Not Significant

Significant (red)

Not Significant (green)

4.2.1 Biotic – Food

4.2.1.1 Cocoa

The result of the decision tree process applied to cocoa found that blockchain technology may be a viable solution depending on the severity of risk involved and the need for visibility in specific circumstances. The evidence of criteria used in assessing the attributes for cocoa is shown in Table 7.

There is limited trust between actors in the cocoa supply chain. For example, Amankwah-Amoah et al. (2018) mention illegitimate activities like smuggling, theft, deceit, and bribery in Ghana that have the potential to undermine trust in the cocoa supply chain. Further, Trienekens (2018) describe how bribery and power abuse are prevalent in the cocoa supply chain leading to limited trust between various actors in the supply chain.

Cocoa farming poses significant social and environmental risks. Around 3.5 million tonnes of cocoa are produced globally every year, with ninety percent of it grown by small-scale farmers who are often exploited, which presents social risks (Fairtrade, 2018). Additionally, cocoa production has several issues like child labour, forced labour and low wages associated with it (Appiah, 2017; Clark, 2020; Hawksley, 2011; Kelly, 2016). According to a 2015 U.S Labor Department Report, more than two million child labourers worked in cocoa plantations (Whoriskey & Georges, 2019) posing social concerns. Several leading chocolate brands have strategies in place to ensure that the cocoa is responsibly sourced (Cargill, 2018; Hensel, 2018). However, there is lack of data on the effectiveness of these strategies in solving problems like child labour in cocoa farming (Camargo & Nhantumbo, 2016). Around forty percent of the cocoa produced in the Ivory Coast, which accounts for more than a third of the world's cocoa, is grown illegally in the country's national parks (Parenti, 2008). The production of cocoa leads to deforestation and loss of biodiversity resulting in environmental concerns (Angel, 2020; Lyngaas, 2016; Maclean, 2018; Whoriskey, 2019).

The cocoa supply chain is complex and spans across different countries (Griek et al., 2010). Ivory Coast, Ghana, Nigeria and Cameroon account for seventy percent of the global cocoa production which is then traded and transported to different countries (Beg et al., 2017). The cocoa supply chain consists of multiple tiers which include collectors, traders, exporters, processors and manufacturers (Griek et al., 2010).

The cocoa industry is open to innovation and has made efforts to trace cocoa and address sustainability issues. For example, 'BeanTracker' is a digital traceability platform based on blockchain to monitor the flow of cocoa beans from Africa to Europe (Davis, 2019). Since no other digital technology is in place to effectively monitor risks in the cocoa supply chain, blockchain may be a viable solution for establishing traceability (Figure 4).

Table 7: Evidence to support the decision-tree for cocoa supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Amankwah-Amoah et al. (2018); Trienekens (2018)
Are there significant sustainability risks?	Yes	Environmental risks according to Whoriskey (2019), Maclean (2018), Angel (2020), and Lyngaas (2016) Human Rights risks according to Hawksley (2011), Appiah (2017), Clark (2020), and Kelly (2016)
Is the supply chain complex?	Yes	Griek et al. (2010)
Does commodity cross national borders	Yes	Beg et al. (2017)
Is the commodity perishable?	Yes	Moisture content of less than eight percent is required for storage of cocoa beans to avoid growth of microbes (FAO, 2013)
Is the commodity demand uninfluenced by seasonal variations?	Yes	Geman & Sarfo (2012)
Does the commodity take greater than one month to reach the end-user?	No	Mota et al. (2019)
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $2.25/kg based on NASDAQ. (2020, March 25). https://www.nasdaq.com/market-activity/commodities/cj%3anmx
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	Yes	Davis (2019)

4.2.1.2 Coffee

The decision tree process applied to coffee found that blockchain technology may be a viable solution for monitoring sustainability risks in the supply chain. The evidence of criteria used in assessing the attributes for coffee is shown in Table 8.

There is limited trust between actors in the coffee supply chain. For example, fraudulent practices such as mixing organic coffee with regular (non-organic) coffee are often carried out in the coffee supply chain which can undermine trust (Brusselaers et al., 2011).

Coffee is one of the most valuable and actively traded agricultural commodities, with one hundred twenty-five million people relying on coffee for their livelihoods (Osorio, 2002). Brazil and Ethiopia, the leading producers of coffee, rely largely on smallholder farmers in the upstream (Jena et al., 2012; Watson & Achinelli, 2008). The surge in demand for coffee globally has made farmers resort to growing methods that have vast implications on sustainability. Coffee growing is strongly linked to deforestation and loss of biodiversity (Blacksell, 2011; Kent, 2019; Kinver, 2019; Scialla, 2015). Traditionally, coffee is grown under a shaded canopy of trees, providing habitat for a wide range of insects and animals and eliminating the need for chemical fertilizers (Blacksell, 2011). However, with the recent increase in market demand, this traditional process has been replaced by growing coffee in the sun for higher yields. Sun-grown coffee does not require forested canopy, which results in the cutting of forests and makes chemical fertilizers a necessity (Blacksell, 2011). In addition to environmental issues, significant human rights violations like illegal hiring of workers have been reported at Brazilian coffee farms leading to social concerns (Teixeira, 2019).

The coffee supply chain is complex and is spread across different countries. The coffee supply chain consists of multiple tiers which includes farmers, traders, exporters, roasters and retailers (Macdonald, 2007; Thiruchelvam et al., 2018). Coffee is an international commodity that is commonly produced in developing countries and is traded in the world market with the actors in the coffee supply chain distributed across the globe (Ibrahim & Zailani, 2010; Lewin et al., 2004).

In spite of coffee beans being a low-value commodity (see Table 8), the coffee industry is fairly open to innovation and has made efforts to trace coffee beans back to the grower. For example, Nestlé has announced its plans to collaborate with IBM Food blockchain platform and Rainforest Alliance to trace their coffee back to its origins (IBM, 2020). Hence, blockchain might be feasible for addressing the sustainability risks in the coffee supply chain depending on the severity of risk involved.

Table 8: Evidence to support the decision-tree for coffee supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Brusselaers et al. (2011)
Are there significant sustainability risks?	Yes	Environmental risks according to Scialla (2015), Blacksell (2011), Kinver (2019), and Kent (2019) Human Rights risks according to Teixeira (2019), Doward (2020), and Lopes (2018)
Is the supply chain complex?	Yes	Macdonald (2007); Thiruchelvam et al. (2018)
Does commodity cross national borders	Yes	Ibrahim & Zailani (2010); Lewin et al. (2004)
Is the commodity perishable?	Yes	Moisture content of 11-12.5 percent is required for storage of coffee beans to avoid growth of microbes (ICO, n.d.)
Is the commodity demand uninfluenced by seasonal variations?	Yes	Wong et al. (2011)
Does the commodity take greater than one month to reach the end-user?	Yes	Ibrahim & Zailani (2010)
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $2.87/kg based on NASDAQ. (2020, March 25). https://www.nasdaq.com/market-activity/commodities/kt%3anmx
Is there digital technology in place to monitor risks?	No	No evidence found in Industry reports
Is the industry open to innovation?	Yes	IBM (2020)

4.2.1.3 Fish

The decision tree process applied to fisheries showed that blockchain may be desirable even though there are challenges that need to be addressed (see Section 5.5). The evidence of criteria used in assessing the attributes for fisheries is shown in Table 9.

The expert mentioned that fraudulent activities carried out in the fisheries supply chain has led to a lack of trust among various actors. Studies have shown that seafood fraud is common which involves mislabeling or substituting one species of fish for another. For example, seafood is mislabeled 25% to 70% of the time for fish like red snapper, wild salmon and Atlantic cod (Warner et al, 2012).

In 2016, global fish production was estimated at 171 million tons, with China being the largest producer of fish (FAO, 2018). Almost half of the global fish production is from small scale fisheries in developing countries where ensuring traceability is a major concern (FAO, 2015). In the past decade, many seafood businesses have been committing to sustainability with the aim of improving traceability in their supply chains to meet their social responsibility goals. However, current traceability systems in the fisheries sector are mostly paper-based and lack end-to-end interoperable electronic recordkeeping systems (Lewis & Boyle, 2017).

The expert stated that the fisheries supply chain was complex with multiple tiers and intermediaries. For example, the fisheries supply chain consists of fishermen, local dealers, exporters, and traders. Further, the expert mentioned that frozen fish could take several months to reach the consumer when it is exported to different countries.

The expert stated that there were efforts being taken to tackle ESG risks and enhance the visibility of activities in the supply chain. For example, 'ThisFish App' is a digital technology platform to maintain traceability of seafood. However, the expert was unsure of the effectiveness of this technology to promote the traceability of the fisheries supply chain. Additionally, the expert stated that the fisheries industry was not open to innovation due to issues like user acceptance and lack of proper technology infrastructure in developing countries. Hence, even though blockchain technology was desirable to tackle sustainability risks, there are challenges that need to be addressed (see Section 5.5).

Table 9: Evidence to support the decision-tree for fisheries supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Brusselaers et al. (2011)
Are there significant sustainability risks?	Yes	Environmental risks according to Batha (2019), Murphy (2017), and McGrath (2019)
		Human Rights risks according to McGrath (2014), Urbina (2015), and McVeigh (2019)
		Governance risks according to Neslen (2015), Chung (2020), and Nixon (2015)
Is the supply chain complex?	Yes	Expert consultation
Does commodity cross national borders	Yes	Expert consultation
Is the commodity perishable?	Yes	Expert consultation
Is the commodity demand uninfluenced by seasonal variations?	Yes	Expert consultation
Does the commodity take greater than one month to reach the end-user?	Varies; frozen fish can take several months to travel through the supply chain	Expert consultation
Is the value of the commodity greater than ten dollars per kilogram?	Yes	Cost is $20.32/kg (for shrimp) based on NOAA Fisheries, (2016, March 17). https://fish.nefsc.noaa.gov/read/socialsci/dataPicker.php
Is there digital technology in place to monitor risks?	Yes	ThisFish App (Future of Fish, 2014)
Is the industry open to innovation?	No	No evidence found in academic literature and media reports

4.2.1.4 Oranges

The decision tree outcome showed that blockchain may not be suitable for managing the oranges supply chain. The evidence of criteria used in assessing the attributes for oranges is shown in Table 10.

The expert mentioned that there was a lack of trust among various actors citing food fraud as an issue present in the fruit supply chain. Studies from the literature also support this finding. For example, there is a possibility of organic oranges being substituted partially or entirely with cheaper products (Johnson, 2014). Additionally, Bremer & Lindqvist (2019) has noted that most organic products like oranges are verified through paper-based traceability systems, which can be falsified.

Sustainability risks are present in the orange supply chain, even though they have not gained international media exposure. The expert stated that there were concerns about unsafe working conditions primarily due to lack of protective gear while applying pesticides in farms. The expert also identified child labour as a concern in several countries where oranges are produced. In Brazil, Mexico, and South Africa, thousands of children are employed in plantations as orange pickers (Finkbeiner, 2011). Further, social concerns like unfair wages and forced labour are prevalent in fruit farms in the U.S (Verite et al., 2010). There have also been reports of workers in Florida and South Africa working overtime in plantations without fair compensation (Raworth, 2004).

The expert mentioned that the orange supply chain is spread across different countries and is complex consisting of farmers, contractors, local traders and wholesalers. Further, Brazil, the largest producer of oranges and orange juice in the world has ninety-five percent of the production shipped abroad (Gallas, 2017).

The expert stated that the orange industry is not open to innovation and there are no industry initiatives in place to promote responsible sourcing of oranges. Additionally, orange is a low-value commodity (see Table 10) according to the criteria used in the research. Hence, on testing the decision tree, it was found that blockchain technology was not needed for tracking activities in the orange supply chain.

Table 10: Evidence to support the decision-tree for oranges supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Johnson (2014)
Are there significant sustainability risks?	No	No evidence found
Is the supply chain complex?	Yes	Expert consultation
Does commodity cross national borders	Yes	Expert consultation
Is the commodity perishable?	Yes	Expert consultation
Is the commodity demand uninfluenced by seasonal variations?	Yes	Expert consultation
Does the commodity take greater than one month to reach the end-user?	No	Expert consultation
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $2.58/kg based on Intercontinental Exchange Futures U.S. (2020, March 25) https://www.theice.com/products/30/FCOJ-A-Futures/data?marketId=5578838&span=1
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	No	No evidence found in academic literature and media reports

4.2.2 Biotic – Non-food

4.2.2.1 Cotton

On testing the decision tree for cotton, it was found that blockchain may be a viable solution for addressing the sustainability issues depending on the severity of risks involved. The evidence of criteria used in assessing the attributes for cotton is shown in Table 11.

The expert mentioned that there is limited trust between actors in the cotton supply chain which is aligned with the findings from the literature. According to Schenk & Almirall (2010), cotton commodity fraud is prevalent in the U.S with fraudulent cotton commodity products easily gaining entry into U.S. ports. The practice of bribery is also common in the cotton industry (Thomas, 2017). For instance, the profits from harvesting cotton goes to a small wealthy section of the society while most of the population remains impoverished (Thomas, 2017). Such fraudulent practices in the cotton industry can undermine the trust of various actors in the supply chain and can impact trade.

The expert stated that the cotton industry faces major social risks at the farm level, like human rights violations. The expert mentioned cases of labour abuses at the gin and forced labour in spinning mills in certain countries. In addition to social risks, there are also environmental risks in the cotton industry (Clifford, 2013; Goldsmith, 2017; Safi, 2016). Cotton farming, which accounts for sixteen percent of global pesticide use, presents a risk of contamination of the environment (FAO, 2015; Goldsmith, 2017; Laville, 2019; Sanghani, 2018). The expert also identified environmental concerns due to excess water use and energy consumption for cotton production.

The expert mentioned that the cotton supply chain is spread across different countries. China and India account for more than fifty percent of global cotton production, which is then exported to different countries (Hudson et al., 2011). The expert also added that the cotton supply chain is complex with multiple tiers consisting of farmers, traders, manufacturers, and exporters.

The expert stated that currently the cotton industry does not use technology like RFID, IoT or other digital tracking software to monitor sustainability risks. However, the expert stated that the cotton industry is progressive and open to innovation. For example, ‘Organic Cotton

Traceability Pilot' uses tracer techniques and blockchain to record cotton supply chain data, thereby providing traceability of cotton from farm to retail (Knapp, 2019).

Table 11: Evidence to support the decision-tree for cotton supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Thomas (2017)
Are there significant sustainability risks?	Yes	Environmental risks according to Laville (2019), Goldsmith (2017), and Sanghani (2018)
		Human Rights risks according to Clifford (2013), Goldsmith (2017), and Safi (2016)
Is the supply chain complex?	Yes	Expert consultation
Does commodity cross national borders	Yes	Expert consultation
Is the commodity perishable?	No	Expert consultation
Is the commodity demand uninfluenced by seasonal variations?	Yes	Expert consultation
Does the commodity take greater than one month to reach the end-user?	No	Expert consultation
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $1.18/kg based on NASDAQ. (2020, March 25). https://www.nasdaq.com/market-activity/commodities/tt%3anmx
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	Yes	Knapp (2019)

4.2.2.2 Palm Oil

The decision tree outcome showed that blockchain may not be suitable for managing the palm oil supply chain. The evidence of criteria used in assessing the attributes for palm oil is shown in Table 12.

The expert mentioned that there was limited trust between actors in the palm oil supply chain. For example, bribery and corrupt activities by transnational logging companies have been documented by various researchers in the palm oil supply chain (Palmer, 2001; Walters, 2010).

Further, the expert stated that the palm oil supply chain had significant environmental risks and social risks associated with it. Clearing of peatlands in Indonesia and Malaysia to make way for palm oil plantations had resulted in environmental degradation leading to forest fires and toxic smoke (Carrington, 2018; Chris Davis, 2014; Mcgrath, 2018). Furthermore, the expert described habitat loss due to clearing peatlands as another environmental concern due to its adverse impact on biodiversity. Social risks like child labour, forced labour and safety concerns were also identified at the plantation level (Al-Mahmoud, 2015; Danubrata & Munthe, 2016; Davies, 2016; Manik et al., 2013; Neslen, 2016). With the expansion of the palm oil industry, sustainability concerns have been raised by NGOs due to the social and environmental ramifications at the plantation level (Harvey, 2020). From the expert consultation, it was also understood that safety risks were also common at the upstream supply chain due to the lack of protective gear while handling toxic chemicals and pesticides, thereby posing a risk to human health.

The expert mentioned that the palm oil supply chain is spread across different countries. For example, Malaysia and Indonesia, account for eighty-five percent of the global palm oil production which is then traded across different countries (Tullis, 2019). Further, the expert added that the palm oil supply chain is complex with multiple tiers consisting of farmers, refiners, exporters, and manufacturers.

The expert mentioned that the palm oil industry was not very open to innovation citing lack of familiarity of upstream actors to a new technology as a barrier that would affect its adoption.

The expert stated that recording transactions on a blockchain platform would be challenging for farmers in developing countries who had limited knowledge of this technology. Further, on testing the decision tree for palm oil, it was found that blockchain may not be suitable for monitoring risks in the palm oil supply chain. This was because palm oil, already had an existing digital traceability platform, ULULA, in place to monitor sustainability risks.

Table 12: Evidence to support the decision-tree for palm oil supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Palmer (2001); Walters (2010)
Are there significant sustainability risks?	Yes	Environmental risks according to Carrington (2018), Mcgrath (2018), and Davis (2014)
		Health & Safety risks according to Davies (2016), Al-Mahmoud (2015), and Danubrata & Munthe (2016)
		Human Rights according to Danubrata & Munthe (2016), Neslen (2016), and Al-Mahmoud (2015)
Is the supply chain complex?	Yes	Expert consultation
Does commodity cross national borders	Yes	Expert consultation
Is the commodity perishable?	Yes	Palm oil requires a storage temperature of thirty-two to forty degree celsius to prevent spoilage (FAO, 2010)
Is the commodity demand uninfluenced by seasonal variations?	Yes	Expert consultation
Does the commodity take greater than one month to reach the end-user?	Yes	Expert consultation
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $0.57/kg based on Bursa Malaysia Exchange. (2020, March 25). https://markets.businessinsider.com/commodities/palm-oil-price
Is there digital technology in place to monitor risks?	Yes	ULULA platform (Liechtenstein Initiative, 2019)
Is the industry open to innovation?	No	No evidence found in academic literature and media reports

4.2.2.3 Rubber

On testing the decision tree for rubber, it was found that blockchain may be a viable solution for addressing the sustainability issues depending on the severity of risks involved. The evidence of criteria used in assessing the attributes for rubber is shown in Table 13.

There is limited trust between actors in the rubber supply chain. For example, Slocomb (2010) has documented faking of documents and bribery in the rubber industry in Cambodia undermining trust of various actors in the supply chain.

Rubber poses significant social and environmental risks to the automotive industry. According to a study by the International Labor Organisation (2010), more than half of the children working in rubber plantations were under fifteen years of age, thereby posing major social concerns like child labour and forced labour. Several rubber glove factories in Malaysia have been linked to social concerns like illegal working hours and unsafe working conditions (Ellis-Petersen, 2018; Guilbert, 2019; Kelly, 2016; Sansa, 2019). Rubber also has a very strong association of incidences of conflict with indigenous peoples due to illegal deforestation and land rights issues (Drive Sustainability, 2018; Gould, 2015; Harford, 2019; Taylor, 2018). The surge in global demand for rubber has led to the destruction of forests and loss of habitat for wildlife (Briggs, 2015).

The supply chain of rubber is complex, consisting of multiple tiers which includes farmers, dealers, processor, manufacturer, and wholesaler (De Haan et al., 2003; Marimin et al., 2014). Further, rubber is a global industry with its supply chain dispersed around the world (De Haan et al., 2003).

Rubber is a low-value commodity, and the industry is not open to innovation as no evidence of initiatives taken by the industry to promote responsible souring could be found in academic literature and media reports. Since there is no digital tracking software to track the rubber supply chain (see Table 13), blockchain may be feasible depending on the severity of risk involved.

Table 13: Evidence to support the decision-tree for rubber supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Slocomb (2010)
Are there significant sustainability risks?	Yes	Environmental risks according to Gould (2015), Harford (2019), and Taylor (2018)
		Human Rights risks according to Kelly (2016), Ellis-Petersen (2018), Sansa (2019), and Guilbert (2019)
Is the supply chain complex?	Yes	De Haan et al. (2003); Marimin et al. (2014)
Does commodity cross national borders	Yes	De Haan et al. (2003)
Is the commodity perishable?	No	Penot (2004)
Is the commodity demand uninfluenced by seasonal variations?	Yes	Chantuma et al. (2009)
Does the commodity take greater than one month to reach the end-user?	No	De Haan et al. (2003)
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $1.5/kg based on Singapore Commodity Exchange. (2020, March 25). https://www.indexmundi.com/commodities/?commodity=rubber&months=300
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	No	No evidence found in academic literature and media reports

4.2.3 Abiotic – Metals

4.2.3.1 Aluminum

The decision tree result for aluminum showed that blockchain might be a feasible solution for addressing sustainability risks in the supply chain, depending on the severity of the risk involved. The evidence of criteria used in assessing the attributes for aluminum is shown in Table 14.

There have been various industrial scandals involving aluminum supply chain fraud that have been mentioned by various researchers (DuHadway et al., 2020; Gwynne, 2019). For instance, two NASA satellite launch missions failed because a key supplier of aluminum provided altered test data on aluminum strength and reliability (DuHadway et al., 2020). These findings show that there is limited trust in the aluminum supply chain.

Aluminum has significant sustainability risks associated with it (Phillips, 2019; Temper, 2015). Bauxite mining activities in Brazil and India have resulted in deforestation and migration of Indigenous people (Cocks, 2017; Phillips, 2018; Thakurta, 2011). Additionally, bauxite mining poses health and safety risks to miners, which includes noise-induced hearing loss, respiratory infections and contamination of drinking water (Dickerman & Albarenga, 2019; Jagger, 2010; Wilkinson, 2010). From a governance perspective, alumina is often produced in countries with the weak rule of law and corruption, which presents governance risks (Drive Sustainability, 2018). Aluminum showed a strong association with four ESG issues: high carbon dioxide emissions, incidences of conflict with Indigenous people, countries with weak rule of law, and countries experiencing corruption (Drive Sustainability, 2018).

The aluminum supply chain is complex and is spread across different countries. The aluminum supply chain consists of multiple tiers which includes miners, refiners, smelters, and traders (OECD, 2019). Australia, China, Brazil, India and Guinea account for eighty-four percent of global aluminum production, which is then exported to various countries (Bray, 2010; Steinrücke, 2011).

The aluminum industry is open to innovation since there are initiatives in place to track aluminum and ensure responsible sourcing. For example, the Aluminum Stewardship Initiative is a global non-profit standards-setting and certification organization that was launched to ensure responsible sourcing of aluminum (Williams, 2017). Since there is no digital technology in place to monitor risks in the aluminum supply chain (see Table 14), blockchain may be suitable for ensuring responsible sourcing of aluminum.

Table 14: Evidence to support the decision-tree for aluminum supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	DuHadway et al. (2020); Gwynne, 2019
Are there significant sustainability risks?	Yes	Environmental risks according to Slezak (2016), Phillips (2018), Knott (2019) and Kiernan (2012)
		Health & Safety risks according to Jagger (2010), Dickerman & Albarenga (2019), and Wilkinson (2010)
		Governance risks according to Thakurta (2011), Phillips (2018), and Cocks (2017)
Is the supply chain complex?	Yes	OECD (2019)
Does commodity cross national borders	Yes	Steinrücke (2011)
Is the commodity perishable?	No	Common knowledge
Is the commodity demand uninfluenced by seasonal variations?	Yes	Hatayama et al. (2012)
Does the commodity take greater than one month to reach the end-user?	Yes	Charan et al. (n.d.)
Is the value of the commodity greater than ten dollars per kilogram?	No	Cost is $1.5/kg based on London Metal Exchange. (2020, March 25) https://www.lme.com/Metals/Non-ferrous/Aluminium#tabIndex=2
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	Yes	Williams (2017)

4.2.3.2 Cobalt

On testing the decision tree for cobalt, it was found that blockchain technology was favorable to address the risks in the cobalt industry. The evidence of criteria used in assessing the attributes for cobalt is shown in Table 15.

The expert mentioned that there is limited trust between actors in the cobalt supply chain. This is mainly because cobalt mining in the DRC is strongly connected to bribery and opaque contracting deals that benefit the country's elite and their international collaborators (Callaway, 2018; Whitman, 2014).

The expert stated that cobalt is a high-value commodity that has significant sustainability risks associated with it. Sustainable mining of cobalt has been an issue of global concern, with NGOs denouncing human rights abuses accompanying artisanal and small-scale mining activities in the DRC which is the largest producer of cobalt globally (Kelly, 2019). Further, the expert mentioned that cobalt mining is strongly associated with health and safety risks, human rights issues and governance risks. Cobalt mining also poses occupational health and safety risks and has resulted in the death and injuries of people working in mines in the DRC (Kelly, 2020). Child labour risks in the cobalt mining industry are also significant, with 2.53 percent of children aged seventeen or under illegally working in the copper-cobalt belt (Drive Sustainability, 2018). There are also governance risks associated with the cobalt supply chain as the top producer countries of cobalt experience high levels of corruption (Drive Sustainability, 2018).

The expert mentioned that the cobalt supply chain is spread across different countries and is complex. According to the expert, most of the cobalt produced in the DRC is then exported to other countries. Further, the expert added that the cobalt supply chain is complex with multiple tiers consisting of miners, refiners, smelters, and traders.

The expert also mentioned that the cobalt industry is also open to innovation as there have been efforts taken by the industry to trace cobalt back to its origin. For example, IBM has partnered with Ford and RCS Global to develop a blockchain platform for ensuring responsible sourcing of cobalt (Ross & Lewis, 2019). This pilot project is aimed at increasing transparency of the cobalt supply chain by recording transactions at every stage of the cobalt supply chain. Hence, blockchain was found to be a feasible solution for the cobalt industry.

Table 15: Evidence to support the decision-tree for cobalt supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Callaway (2018); Whitman (2014)
Are there significant sustainability risks?	Yes	Health & Safety risks according to Cellan-Jones (2016), Watts (2019), and Frankel (2016)
		Human Rights risks according to Cellan-Jones (2016), Watts (2019), and Frankel (2016)
		Governance risks according to Shabalala & Desai (2019), Kelly (2019), and Frankel (2016)
Is the supply chain complex?	Yes	Expert consultation
Does commodity cross national borders	Yes	Expert consultation
Is the commodity perishable?	No	Expert consultation
Is the commodity demand uninfluenced by seasonal variations?	No	Expert consultation
Does the commodity take greater than one month to reach the end-user?	Yes	Expert consultation
Is the value of the commodity greater than ten dollars per kilogram?	Yes	Cost is $29.5/kg based on London Metal Exchange. (2020, March 25). https://www.lme.com/en-GB/Metals/Minor-metals/Cobalt#tabIndex=2
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	Yes	Ross & Lewis (2019)

4.2.3.3 Tin

On testing the decision tree for tin, it was found that even though blockchain was desirable to monitor the risks in the tin industry, there are challenges that need to be overcome (see Section 5.5). The evidence of criteria used in assessing the attributes for tin is shown in Table 16.

There is limited trust between actors in the tin supply chain. There have been reports about corrupt practices and bribery in the upstream of the tin supply chain, suggesting lack of trust (Hodge, 2016).

Tin is a high-value commodity with significant sustainability risks associated with it. The expert identified contamination of beaches as one of the environmental concerns of tin mining. Additionally, tin mining has resulted in the destruction of coral reefs and wildlife habitats (Asmarini & Christina, 2020; Morris, 2013). The use of tin is also linked to environmental risks, health and safety risks, human rights risks and conflict risks (Bilton, 2014; Bujakera & Ross, 2019; Collyns, 2014). Since the bulldozing of land is required for tin mining, deforestation is another issue of environmental concern in the tin industry (Hodal, 2012). Furthermore, the expert identified social risks like child labour and forced labour associated with artisanal and small-scale mining in the tin industry. Bangka Island in Indonesia, which accounts for ninety percent of Indonesia's tin, was reported to be highly unsafe due to lack of safety measures for workers involved in tin mining leading to several accidents (Hodal, 2012; Ross & Lewis, 2019). Tin mining in the DRC also has high conflict risks associated with it due to the financing of warfare from illegal mining activities (Dailey, 2012; Desai & Ross, 2019; Moodie, 2014).

The expert mentioned that the tin supply chain is spread across different countries and is complex. Further, the expert added that the tin supply chain is complex with multiple tiers consisting of miners, refiners, smelters, traders, and manufacturers.

The expert stated that the tin industry was not open to innovation and did not have any blockchain pilot projects in place to monitor risks. Hence, blockchain could be a viable solution for the tin industry even though there are challenges that need to be overcome (see Section 5.5).

Table 16: Evidence to support the decision-tree for tin supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Hodge (2016)
Are there significant sustainability risks?	Yes	Environmental risks according to Hodal (2012), Morris (2013), and Asmarini & Christina (2020)
		Health & Safety risks according to Bilton (2014), Collyns (2014) and Bujakera & Ross (2019)
		Human Rights risks according to Hodal (2013), Ross & Lewis (2019) and Bilton (2014)
		Conflict risks according to Moodie (2014), Desai & Ross (2019) and Dailey (2012)
Is the supply chain complex?	Yes	Expert consultation
Does commodity cross national borders	Yes	Expert consultation
Is the commodity perishable?	No	Expert consultation
Is the commodity demand uninfluenced by seasonal variations?	Yes	Expert consultation
Does the commodity take greater than one month to reach the end-user?	Yes	Expert consultation
Is the value of the commodity greater than ten dollars per kilogram?	Yes	Cost is $13.72/kg based on London Metal Exchange. (2020, March 25). https://www.lme.com/en-GB/Metals/Non-ferrous/Tin#tabIndex=2
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	No	No evidence found in academic literature and media reports

4.2.4 Abiotic – Non-metals

4.2.4.1 Diamonds

On testing the decision tree for diamonds, blockchain technology was found to be suitable for mitigating the risks in the supply chain. The evidence of criteria used in assessing the attributes for diamonds is shown in Table 17.

Corrupt practices in the diamond industry undermine the trust of various actors in the supply chain. For example, evidences of scandals such as accepting bribes for inflating the quality of diamond in grading reports were mentioned in the literature (Lee et al., 2014; Siegel, 2011). The Kimberley Process Certification Scheme was established to ensure responsible sourcing of diamonds. However, the effectiveness of the Kimberley Process Certification Scheme was limited due to fraudulent activities and lack of political will among member states (Armstrong, 2011; Marr, 2018).

The diamond mining industry is often associated with human rights abuses, safety concerns and conflict risks (Marr, 2018). There have also been reports of child labour and unsafe working conditions in diamond mines in the DRC putting the reputation of the diamond industry at risk (Guilbert, 2019; Rhode, 2014; Wiseman, 2019). In the DRC, these ‘blood diamonds’ are illegally traded and used to finance warfare (Armstrong, 2011; Flynn, 2014; Gibb, 2016).

The diamond supply chain is spread across different countries. The top three diamond producing countries in the world are Russia, Botswana and the DRC from where the diamonds are transported to major cutting centres located in Israel and India (Abhyankar, 2012; Bieri, 2013; Grant, 2012). The polished diamonds are then exported to rest of the world from these cutting centres. The diamond supply chain is also complex and consists of several activities such as mining, sorting, cutting, and polishing (Paes, 2005).

The diamond industry is open to innovation as there have been efforts taken to ensure ethical sourcing of diamonds. For example, Everledger, a London based company, uses blockchain to verify the provenance of diamonds by recording activities in the diamond supply chain from the mine to the jeweller (Kshetri, 2018; Volpicelli, 2018). Another example is the blockchain platform Tracr that is set up by the company De Beers to verify the legitimacy of diamonds (Bouw, 2019).

Table 17: Evidence to support the decision-tree for diamonds supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Lee et al. (2014); Siegel (2011)
Are there significant sustainability risks?	Yes	Health & Safety risks according to Rhode (2014), Wiseman (2019), and Armstrong (2011)
		Human Rights risks according to Rhode (2014), Guilbert (2016), and Armstrong (2011)
		Conflict risks according to Flynn (2014), Gibb (2016), and Armstrong (2011)
Is the supply chain complex?	Yes	Paes (2005)
Does commodity cross national borders	Yes	Abhyankar (2012); Bieri (2013); Grant (2012)
Is the commodity perishable?	No	Common knowledge
Is the commodity demand uninfluenced by seasonal variations?	Yes	Tailby (2002)
Does the commodity take greater than one month to reach the end-user?	Yes	Gotthelf (2005)
Is the value of the commodity greater than ten dollars per kilogram?	Yes	Cost is $27,000,000-155,000,000 (approximately) based on International Diamond Exchange. (2020, March 25). http://www.idexonline.com/diamond_prices_index
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	Yes	Kshetri (2018); Volpicelli (2018)

4.2.4.2 Mica

On testing the decision tree for mica, it was found that blockchain technology is desirable for the mica industry, even though there are challenges that need to be addressed (see Section 5.5). The evidence of criteria used in assessing the attributes for mica is shown in Table 18.

There is limited trust between actors in the mica supply chain For example, there have been reports of dealers and local suppliers selling illegally mined crude mica and carrying out fraudulent practices undermining the trust of actors in the supply chain (Giridih, 2007).

Mining of mica poses severe humanitarian risks in addition to health and safety concerns. Child labour is also common in the mica mining industry. For example, in some areas of India, around twenty thousand child labourers were found working illegally in mica mines (Drive Sustainability, 2018). The mine collapses reported in various parts of India have led to the death of several children in unregulated mines (Bhalla et al., 2016). Sixty-two percent of the total mica mining workforce in Madagascar, another major producer, was comprised of children (Hodal, 2019).

The mica supply chain is complex and is spread across different countries. The mica supply chain consists of multiple tiers which includes miners, refiners, smelters, and traders (Bliss, 2017). Fifty percent of mica exports from India, the largest producer of mica, goes to China which is then routed to Europe and the US (Bliss, 2017).

Table 18: Evidence to support the decision-tree for mica supply chain

Question	Does it meet criteria?	Source/Comment
Is there trust between actors in the supply chain?	No	Giridih (2007)
Are there significant sustainability risks?	Yes	Health & Safety risks according to Hodal (2019), Bhalla et al. (2016), and Cavazuti et al. (2019)
		Human Rights risks according to Hodal (2019), Bhalla et al. (2016), and Cavazuti et al. (2019)
Is the supply chain complex?	Yes	Bliss (2017)
Does commodity cross national borders	Yes	Bliss (2017)
Is the commodity perishable?	No	Common knowledge
Is the commodity demand uninfluenced by seasonal variations?	Yes	Tanner (2000)
Does the commodity take greater than one month to reach the end-user?	No	SOMO (2018)
Is the value of the commodity greater than ten dollars per kilogram?	Yes	Cost is $1000-2000 (approximately) based on Wired Magazine. (2015). https://www.wired.co.uk/article/mica-illegal-mining-india
Is there digital technology in place to monitor risks?	No	No evidence found in industry reports
Is the industry open to innovation?	No	No evidence found in academic literature and media reports

Chapter 5: Discussion

This chapter addresses the research question posed in Section 1.2.2. The analysis of the results and their significance to various companies who wish to adopt blockchain technology for responsible sourcing are also discussed. Furthermore, this chapter provides recommendations on integrating blockchain in assurance programs. The barriers to adopting blockchain technology and the limitations of the research are also presented, along with opportunities for improvement.

5.1 Patterns and Trends

The research question in this study was: "What attributes of commodity supply chains make them amenable to blockchain solutions?" On testing the decision tree for the twelve commodity supply chains, certain patterns were observed in the results. Decision tree results for most of the biotic commodities suggest that either blockchain technology is not a practical solution for responsible sourcing or point to the need for blockchain only if the severity of the sustainability risks is high. These commodities being low value might not be amenable to blockchain because despite the value added by blockchain in providing transparency of the supply chain, adopting this technology might not be feasible from an economic perspective. In contrast, the decision tree results for most of the abiotic commodities show that blockchain is either a feasible solution or is desirable for responsible sourcing despite the challenges involved in its adoption. The reasons for this observed pattern are the high value of these commodities and the openness of some of these industries to innovation, which makes blockchain suitable for responsible sourcing in these commodity supply chains.

In two cases, the results align with known blockchain projects that are already in place to support responsible sourcing of high-risk commodities: cobalt and diamonds. In these cases, the decision tree lead to the outcome that blockchain is suitable for assuring responsible sourcing. IBM launched the ‘Responsible Sourcing Blockchain Network’ in partnership with Ford Motor Company to track cobalt through the supply chain (Lewis, 2019). Everledger, a startup, is using blockchain technology to create a permanent digital record of the transactions in the diamond supply chain from mine to consumer (Volpicelli, 2018). These projects show that blockchain may be suitable for industries open to innovation, if the commodity is of high value and has significant supply chain risks associated with it.

In only two of the commodities cases considered (oranges and palm oil), the results showed that blockchain might not be a practical solution for responsible sourcing. In the case of the orange industry, even though the expert mentioned sustainability risks, no evidence of significant sustainability risks was found on reviewing media sources according to the criteria used in this research. A reason for this could be that the assessment of risks was limited to international media reports and did not cover local media sources. Further, only reports in English were considered for the analysis. Currently, the orange industry does not use blockchain to monitor sustainability risks, which aligns with the results in the study. However, in the case of palm oil, Bext360, a blockchain company, is working towards digitalizing the supply chain of palm oil to enhance traceability (Clancy, 2019; Kshetri, 2018). This is counter to the findings of the research which suggests that blockchain was not suitable for addressing the sustainability issues in the palm oil supply chain. This analysis hinged on two reasons: First, palm oil is a low-value commodity. Second, the expert stated that the palm oil supply chain already had a digital technology platform, ULULA, that is being used in some regions to monitor sustainability risks. The effectiveness of this existing digital technology platform was not assessed in the study, which could be a possible reason for the discrepancy between results and known practice.

From the results, and the review of industry information from experts and reports, it was clear that significant sustainability risks occur in the upstream of the palm oil supply chain. This supports the findings of previous studies, notably Brink et al. (2019), Hofmann et al. (2014), and Young (2015). Hofmann et al. (2014) have identified risks due to social issues, ecological issues, and ethical business conduct issues in the upstream supply chain. The supply chain due diligence approach for conflict minerals also focuses on the upstream supply chain as most of the social risks are concentrated in the upstream (Brink et al., 2019; Young, 2015). Therefore, there exists a need for greater transparency in the upstream of the supply chain to mitigate sustainability concerns.

5.2 Meeting Research Objectives and Purpose

The research objective was to explore generic attributes of commodity supply chains that make them easier or harder to assure and align with blockchain technology. This research has synthesized and elaborated on the existing academic and grey literature to identify supply chain attributes that could potentially influence the use of blockchain technology. A framework was developed to guide the research by classifying attributes into four main categories (market structure, product characteristics, geographical scope, and industry considerations). These attributes played an important role in developing the decision tree tool in this research. Previous studies that have focused on the applications of blockchain in sustainable supply chain management have considered only a few attributes, specifically trust in the buyer-supplier relationship, complexity, and risks in the supply chain (Saberi et al., 2018). Along with attributes considered in previous studies, this study systematizes and investigates additional attributes that could potentially affect the assurance of commodity supply chains using blockchain.

The purpose of this research was to explore the contribution of blockchain technology to the domain of sustainability. The results of this study showed that attributes present in blockchain technology may align with addressing sustainability risks in supply chains. Using the decision tree that was developed and researching the potential uses of blockchain technology in sustainable supply chain management, the purpose of this study has been achieved.

5.3 Implications for Downstream Companies

Even though most of the supply chain risks are present at the upstream, it is worth noting that the benefits of using blockchain technology are most likely evident at the downstream. This is because firms at the downstream level are more likely to face reputational losses. According to King & McDonnell (2012), "high-status" firms are more likely to be targeted by activists in comparison to companies with low-reputation. It is important to consider the brand value of the downstream company and the risk of reputational losses due to sustainability issues in the supply chain. Blockchain technology could potentially ensure that responsible companies protect brand value by recording information in a fair and transparent manner.

In this study, the supply chain governance strategy of a company was not considered as an attribute in the decision tree analysis. However, the supply chain governance strategy could be an important consideration for managing risks and for a company prior to adopting blockchain technology. In vertically integrated supply chains, where a single entity owns or tightly controls the whole supply chain, there is a greater potential for trust to be “inherent”; therefore, adopting blockchain technology might not be needed. This is because raw material manufacturing and distribution in vertically integrated supply chains are controlled by a single unit, which may eliminate the relevance and value for a decentralized database like blockchain. This also aligns with the decision tree outcome for the orange supply chain which suggests that blockchain might not be needed. According to the expert, one of the dominant business models in the orange industry involves the producer maintaining ownership from the farm to the wholesaler. The supply chain governance strategy of this model is vertically integrated, which may eliminate the need for blockchain.

Conversely, horizontally integrated supply chains, where multiple actors participate in the supply chain more as equals or even in competition, there is likely a stronger potential benefit from the transparency provided by blockchain (Kelley, 2020). In such a case, there is more likely an absence of trust between the various actors, which may make blockchain suitable to establish traceability in the supply chain (Kelley, 2020; Pflaum et al., 2018).

5.4 Opportunities for Improvement of the Decision Tree

There are several opportunities for improvement of the decision tree model to make the tool more accurate for assessing the practicality of blockchain solutions. The decision tree tool used in this research was developed for commodity supply chains. In the case that this tool is to be used for products, it would need to be revised with additional questions that address the brand value of the downstream firm. Each stage of the supply chain adds value to the product which then becomes associated with the downstream firm. For instance, there is an increase in the value of cotton as it transitions from fibre to final garment in the supply chain. The final garment is often linked to the downstream firm which could face reputational losses in the event of sustainability concerns. An example of this is the leading fashion retailer H&M which is a downstream firm that came under scrutiny for sourcing cotton from companies that maintained unethical labor conditions (Siegle, 2012).

The supply chain governance strategy (i.e vertical integration and horizontal integration) of the company was not considered during the development of the decision tree in this research. If the decision tree is revised, this should be an important consideration as the supply chain governance strategy could influence the outcome of the decision tree (see Section 5.3).

Even though this decision tree was developed as a generic guide for testing the applicability of blockchain technology in supply chains for sustainability, modifications might be needed depending on the type of commodity or product tested. For instance, all the food commodities tested in the study were perishable. Even though this study did not look at food safety risks, the transparency and traceability provided by blockchain would be of value to companies wishing to use blockchain for food safety control. Perishable food is more likely to be prone to safety risks due to deterioration of quality if ambient environmental conditions are not monitored (Holley & Patel, 2005; Tsang et al., 2019). Several researchers have also noted the potential of blockchain technology for food safety control in perishable food (Tsang et al., 2019; Tse et al., 2017). Hence, it would make sense to reorder the decision tree and evaluate the perishability attribute before the monetary value for food commodities.

5.5 Barriers to Blockchain Integration in Supply Chains

In many of the commodity supply chains considered here, like fisheries, tin and mica, even though the attributes point to a need for blockchain, there are challenges that need to be addressed. First, a lack of familiarity with the actors to a novel solution like blockchain is a challenge. This type of technology may be especially unfamiliar to smallholders like artisanal and small scale miners, farmers, and fishers in the upstream supply chain (Calvao & Gronwald, 2019; Howson, 2020; Kos & Kloppenburg, 2019). For instance, projects like DELVE and CRAFT have documented this problem in artisanal and small scale mining activities (CRAFT, 2018; Delve, 2020). The issue of user acceptance, therefore, poses a barrier to the success of a blockchain solution in supply chain management (Baur et al., 2015). To integrate blockchain technology in supply chain management, it is necessary that actors who have proper knowledge of blockchain are at each stage of the supply chain. Since blockchain technology is new, a lack of proper knowledge among the public can affect its use.

Second, most of the upstream activities in supply chains generally take place in developing or less developed countries where there may be limited access to technology. To use blockchain technology for assurance, it is necessary to have certain IT infrastructure in place. However, this can be infeasible in remote areas (Abeyratne & Monfared, 2016). For instance, Calvao & Gronwald (2019) assert that blockchain projects like Everledger which aims at ensuring diamond provenance might not be accessible to ASM miners in Africa due to technical difficulties. Hence, extending blockchain technology across the various stages of the supply chain can be a challenge, especially in developing and underdeveloped countries.

Another barrier is the high cost involved in adopting blockchain technology. On testing the decision tree for the supply chains of low-value commodities like cocoa, coffee, cotton, rubber and aluminum, it was found that blockchain might be suitable depending on the severity of risks involved. The severity of risks could be assessed by evaluating the trade-off between media attention received for sustainability issues in the respective industries to the value of the commodity. This is because these commodities (cocoa, coffee, cotton, rubber and aluminum) are low-value and blockchain may be feasible only if the benefits of adopting blockchain outweigh the costs. For example, cocoa, coffee, and cotton have blockchain projects in place to keep track of the activities in their supply chains due to the severity of risks. However, the cost of adopting a digital technology like blockchain may be a major challenge for actors in these commodity supply chains.

5.6 Recommended Models for Using Blockchain in Supply Chain Assurance

Synthesizing the results with literature on existing supply chain assurance practices and reflecting on blockchain technology, two models are proposed for facilitating the transition to a blockchain-based auditing system: **1) hybrid model** and **2) digital model**. These models could be used by companies that wish to use blockchain technology for supply chain assurance. The two proposed models have been compared to the traditional supply chain auditing process using the guidelines described in Section 2.2 (see Table 19).

Table 19: Comparison between traditional supply chain auditing and the two proposed blockchain models

Principles of auditing	Traditional supply chain audit	Hybrid model	Digital model
Integrity	Auditor carries out unbiased assessments	Auditor verifies data stored on blockchain	Merkle tree in blockchain ensures data **integrity**
Fair presentation	Auditor reports findings honestly	Auditor checks if all the transactions on the blockchain are valid and have been accounted	**Immutability** of data stored in blockchain makes it difficult to alter transactions once boarded on to blockchain
Professional care	Auditor is competent and has technical knowledge to conduct audits in a professional manner	Auditor who has good technical knowledge goes through the transactions stored on the blockchain and checks for discrepancies	**Smart contracts** in a blockchain automate transactions based on a pre-defined logic. Actions are automatically executed in a timely manner based on the defined protocols
Confidentiality	Auditor ensures that the audit findings are not disclosed to third parties.	Auditor ensures that the information stored on the blockchain is not disclosed for personal gains	The transactions on the blockchain are **secured** through cryptography using a private key
Independence	Auditor maintains objectivity and has minimal external influence	Auditor is independent and reports findings based on the data stored in blockchain in an unbiased manner	The **automated** nature of smart contracts and **decentralization** in blockchain removes the risk of bias.
Evidence-based approach	Auditor has samples of verifiable evidence	Auditor presents findings based on information stored in the blockchain	Blockchain is a **distributed ledger** where information is stored which serves as evidence

Companies seeking to prevent reputational losses are highly dependent on auditors who provide information about supply chain performance. However, scandals like the Rana Plaza building collapse, which killed over one thousand workers in Bangladesh, despite being certified by the auditors, make the public question the validity of the information presented by auditors (Sinkovics et al., 2016). Many social problems like low wages, child labour and long working hours are also often not detected by auditors due to the complexity of the supply chain

(Short et al., 2016). The consequence is poor clarity in the incorporation of sustainability into supply chain paradigms.

To mitigate sustainability concerns raised by NGOs, it is important that supply chain auditing is carried out in a fair and transparent manner (LeBaron et al., 2017). Existing sustainability database platforms for social and environmental auditing, like the Business Social Compliance Initiative in the textile supply chain, are often criticized for lack of transparency of data (Merk & Zeldenrust, 2005). Several studies have highlighted how companies could potentially benefit by integrating blockchain into their supply chain auditing practices (Abeyratne & Monfared, 2016; Apte & Petrovsky, 2016; Francisco & Swanson, 2018). However, the nascency of blockchain technology makes its application in supply chain assurance challenging.

Traditional supply chain audits are commonly used for assessing suppliers' ethical and environmental performance. These audits often include assessment questionnaires and site inspections (Gonzalez-Padron, 2016). In a traditional supply chain audit, the auditor is expected to present the findings in a fair and honest manner devoid of any bias. However, previous research suggests that auditors' decisions are often influenced by factors like ongoing client relationships, auditor tenure, and gender (Short et al., 2016). The transparency and data integrity provided by a blockchain system may be beneficial in such cases.

In the hybrid model, blockchain technology can be used by various actors for recording transactions and provides another layer of protection in addition to the auditors. With blockchain, auditors can alert concerned parties about discrepancies in a better manner as the information once recorded on the blockchain cannot be changed. Also, by using a distributed ledger, the auditor's role becomes relatively simple as the documentation is securely stored in one location, making the review process easy.

In the digital model, blockchain technology can be solely relied upon for the auditing process. Using blockchain, each actor in the supply chain will verify the transaction made by the previous actor and will proceed only if the transaction posted meets the specified requirements. Due to the transparent nature of blockchain, the need for auditors is eliminated as the various actors monitor the supply chain. This model ensures a completely decentralized process for tracking the activities in the supply chain using blockchain technology. Further, this digital model could enhance veracity of data and improve the level of confidence decision-makers have in the collection and analysis of sustainability data (Castka et al., 2020). It is also possible that this enhanced veracity provided by blockchain can help companies adopt a proactive approach for managing the sustainability risks in the supply chain (Castka et al., 2020). For example, the data provided by blockchain could help in monitoring risks and can alert stakeholders since this data is visible to multiple parties through the property of decentralization.

Blockchain technology is most useful when there is limited trust between the various users (Werbach, 2018). In hybrid model, it becomes necessary to trust the third party, which is the auditor. Also, the property of immutability is unique to blockchain and cannot be seen in traditional supply chain auditing, which may be vulnerable to fraudulent practices. This model can be used in the transition phase while migrating to digital model. During this transition phase, any errors in the blockchain-enabled supply chain auditing model can be rectified as auditors verify the information on the ledger.

Essentially, blockchain is a distributed ledger with decentralization being one of its key properties. On comparing the two proposed models of blockchain, it is seen that the digital model is decentralized and is based solely on smart contracts that can be vulnerable. In contrast, the hybrid model relies on intermediaries like auditors for verification of data in the blockchain system and does not ensure a completely decentralized system.

Digitalization of the supply chains using blockchain technology is still in its infancy. Currently, it might not be possible for blockchain technology to completely replace traditional auditing practices due to the various barriers discussed in Section 5.5. For instance, lack of familiarity of the actors in the supply chain to blockchain may hinder its successful adoption in hybrid model and digital model. However, it is possible that with time, blockchain technology can be extended as an assurance tool replacing conventional auditing systems.

5.7 Contributions to Literature and Industry

This study expands upon existing literature to assess the potential use of blockchain technology in sustainable supply chain management. Although the extant literature provides some initial exploration of how blockchain technology can be used in responsible sourcing of supply chains, there has been very little work done to examine how real supply chains can or cannot utilize blockchain. This study identifies generic attributes of commodity supply chains from the literature and presents a framework for analyzing supply chain attributes relevant to blockchain technology. Additionally, very few studies have assessed sustainability risks across a diverse range of commodities. For example, Drive Sustainability (2018) presents a comparison of the ESG risks of materials used in the automotive industry and electronics industry. However, previous studies have not assessed sustainability risks across different categories of commodities such as food, non-food, metals and non-metals. This research makes an original contribution to literature by addressing this gap and comparing the significance of sustainability risks for a broad range of commodities. A major contribution of this study is the development of the decision tree tool to assess the suitability of blockchain solutions for responsible sourcing in supply chains. By testing the decision tree, the specific attributes of commodity supply chains that make them amenable to blockchain solutions are identified.

This study also identifies the barriers to introducing blockchain technology for responsible sourcing in commodity supply chains. If the identified barriers are addressed, blockchain technology could be introduced to assure the legitimacy of the information presented to various stakeholders. The recommendations and strategies proposed to establish traceability by considering two models could be beneficial to companies wishing to incorporate blockchain technology for supply chain auditing and assurance.

5.8 Limitations

An initial limitation of this study was the scarcity of scholarly literature related to the use of blockchain for responsible sourcing in supply chains. This is mainly because blockchain is a nascent technology, and most of the blockchain projects are still in the pilot stage. Another limitation is related to the criteria used for assessing certain attributes. Certain thresholds had to be established for assessing certain attributes which was based on the author’s judgement.

The scope of analysis for this study was broad and looked at global commodities. The data collected was also generalized which may be a limitation for diverse commodity supply chains like fisheries as certain information might not be captured. This is because there is a possibility that the data gathered from experts and document analysis may focus only on a part of the industry and may not give a complete picture. Commodity definitions were in some cases not clear. For example, fish could have been broken into multiple commodities. Based on results for costs and perishability, for example, this sector has a wide range of attributes. The characteristics could have been better understood and analyzed if the broad category was broken down. For example, only shrimp was assessed while using the decision tree for fisheries sector. Hence, the results may not be precise as the subtleties of commodity supply chains are not taken into account. Further, since the temporal scope of this research is defined by the current market and supply chain practices, there is a possibility that the findings may vary if this study is carried out at a different time frame.

Availability of experts was also a limitation for assessing some of the commodity supply chains. For these supply chains, secondary data was the sole source of information. Despite these limitations, this study makes a significant contribution to an under-researched domain.

Chapter 6: Conclusions

With an increasing number of firms committing to corporate social responsibility, the pressure to source raw materials responsibly has also increased. Companies have been working on increasing the visibility of supply chain activities to mitigate reputational losses due to environmental and social risks. Several companies are adopting blockchain technology to improve the transparency of their supply chain. However, there has been very little research done on the suitability of blockchain technology for improving sustainability in supply chains.

The potential use of blockchain technology as an assurance tool for responsible sourcing in supply chains is explored in this research. This study condenses the scattered literature on supply chain attributes that could potentially influence the adoption of blockchain and presents a framework that connects these attributes to blockchain technology. The main contribution of this study is the development of the decision tree tool that can be used to analyze if blockchain is appropriate for managing a commodity's supply chain. This tool was then tested for twelve different commodity supply chains, and the findings are presented.

The results showed that certain commodity supply chains were amenable to blockchain solutions while others were not. Blockchain could be a practical solution for ensuring responsible sourcing in the cobalt and diamond supply chain while the results show that it may not be suitable for the orange and palm oil supply chain. The results also suggest that blockchain technology may be desirable for fish, tin, and mica if the challenges involved in adopting this technology are addressed. Furthermore, the results indicate that blockchain might be suitable for aluminum, cocoa, coffee, cotton, and rubber depending on the severity of risks.

This study provides recommendations to integrate blockchain technology into supply chain assurance by suggesting two models. Hybrid model uses auditors for verification of data on the blockchain system while digital model relies solely on blockchain for assurance. These recommended models could potentially benefit companies interested in transitioning to a blockchain based assurance system.

This research has been one of the first studies to relate supply chain attributes of a commodity with blockchain technology. This study also makes a significant contribution to literature by assessing supply chain risks across a wide range of commodities. The findings in the study provide new insights into the practical applications of blockchain in sustainable supply chain management. Furthermore, opportunities for improvement of the decision tree tool have been suggested along with direction for future research. Some of these areas include addition of attributes like brand value and supply chain governance strategy of the company; and modification of the decision tree based on the type of commodity evaluated.

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Appendices

Appendix A: Supplementary Figures

The Material Change report by Drive Sustainability (2018) was used to understand the ESG risks associated with aluminum, cobalt, tin and mica.

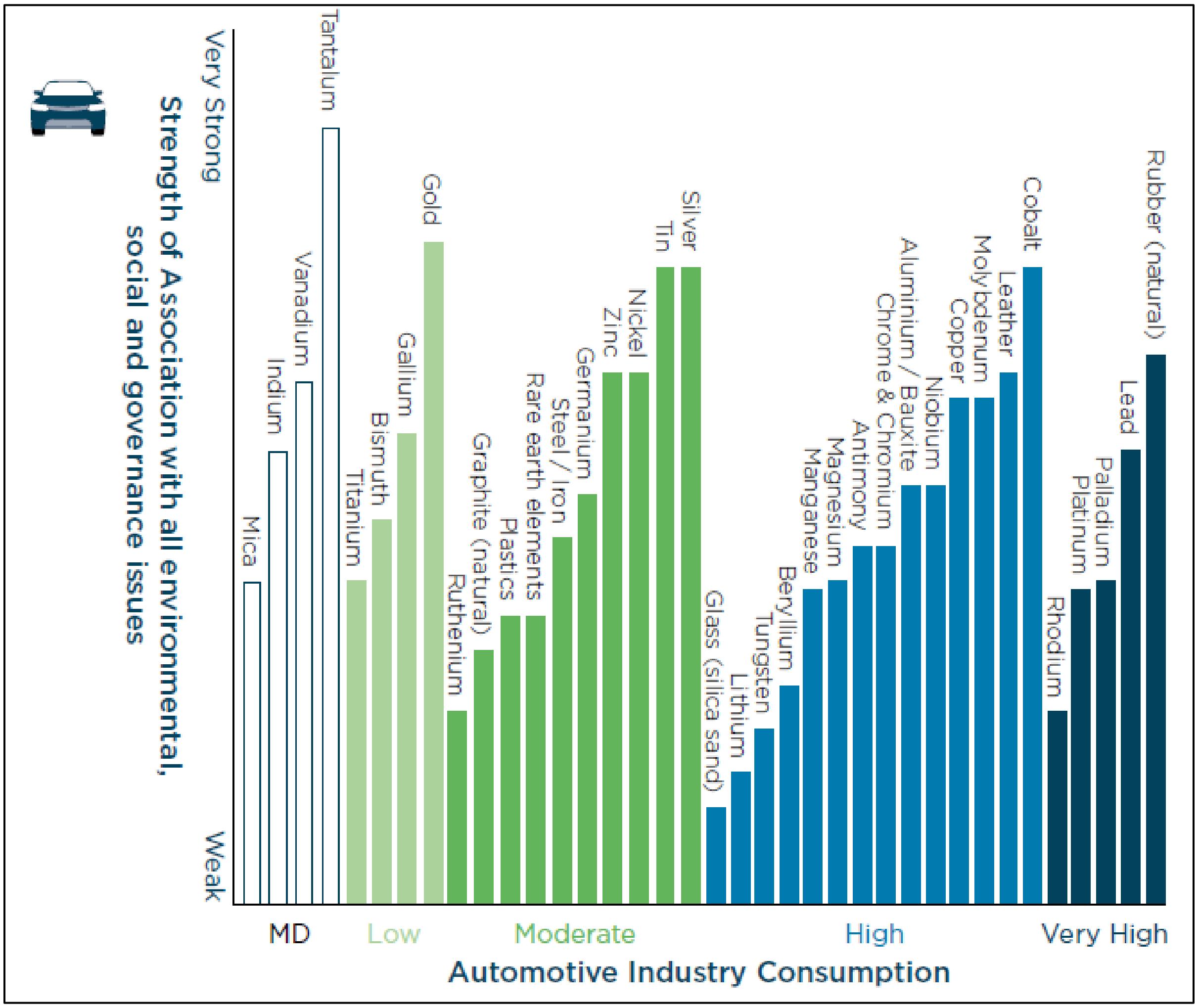

Figure A1: Ratings of materials by industry % of total global consumption and association with all ESG issues. Source: (Drive Sustainability, 2018)

Appendix B: Context for Experts

Prior to testing the decision tree, the experts were asked the following questions to clarify the context of discussion before assessing the commodity supply chains using the decision tree.

1. What is the commodity being evaluated?
2. Are there any risks involved in the commodity's supply chain? If so, where do these issues prevail in the supply chain?
3. What is the scope of the supply chain under consideration?
4. Is this industry familiar with a documented system of auditing?
5. Is there an opportunity to improve traceability in the supply chain of this commodity?
6. What is the purpose/motivation behind evaluating this commodity's supply chain?