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Blockchain Characteristics for Sustainable Supply Chain Visibility

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Abstract

Visibility plays a crucial role in sustainable supply chains. A sustainable supply chain is a system of stakeholders, information, and resources involved in flow of a good or service from supplier to customer with considerations for the environment, society and economic performance. In those chains, visibility concept captures the extent to which actors within a sustainable supply chain have access to, or share, mutually benefiting information that is key or useful to their operations and supports decision making taking into cognizance the three-bottom line of economic, social and environment. Support for improved sustainable supply chain is increasing, particularly in the areas of technological advances. This paper focuses on blockchain technology and explores the characteristics of sustainable supply chain visibility and those of blockchains. Key blockchain characteristics found in the literature and those of the sustainable supply chain visibility characteristics were highlighted. The relation between blockchain and sustainable supply chain characteristics were then explored. The results show that sustainable supply chain visibility is multifaceted and can be characterized around green absorptive capacity, green dynamic capabilities, and context. The blockchain characteristics that help support visibility in sustainable supply chains can be aligned to the sustainable supply chain visibility characteristics discussed.

Keywords
Sustainable Supply Chain Management, Visibility, Blockchain, Characteristics.

1. Introduction

A supply chain is a network between a focal company, its suppliers, and customers engaged in producing and distributing specific products and/or services. With the recognition of the need to be sustainable comes the notion of sustainable supply chains. A sustainable supply chain is a system of stakeholders, information, and resources involved in flow of a good or service from supplier to customer with considerations for the environment, society and economic performance. A cornerstone of supply chains is visibility i.e. the extent to which actors within the supply chain have access to timely and accurate information that they consider to be key or useful to their operations (Barratt and Barratt, 2011).

Having appropriate level of visibility across an entire supply chain enables supply chain partners to achieve a higher level of market responsiveness and mitigate the risk of disruptions to the flows of materials and products (Wei and Wang, 2010). Lack of visibility in a supply chain presents a significant challenge to the chain and it can be problematic for achieving desirable competitive advantage. For sustainable supply chains, a lack of visibility can also hinder the chain from holistically achieving its sustainability objectives.

Progress is being made in addressing the challenges of attaining appropriate levels of visibility in supply chains. There is an increasing understanding of the cause and effect of visibility in sustainable supply chains, identification of common supply chain visibility metrics, and clearer definition of the characteristics of supply chain visibility. These advances alleviate the difficulty in promoting visibility projects in supply chains and in evaluating its effectiveness.

Advances in digital technologies are also beneficial to sustainable supply chain visibility development. One of such technologies, of interest in this paper, is blockchain.

Basically, in a literary sense, a blockchain is a chain of blocks in which the blocks are digital pieces of information and the chain refers to its storage in a database. Primarily, a block in a blockchain stores information about a) transactions b) who is participating in transactions, and c) differentiation from other blocks. Blockchain provides a decentralized and distributed public ledger for all the participating parties. The blockchain has come to be recognized as a driver of digital economy with applications is a wide variety of domains including in supply chains (e.g. Kshetri 2018, Feng, 2020). Blockchains introduced serious disruptions to supply chains and other traditional business processes since previously required centralised architectures or trusted third parties to verify them are now possible to be accomplished decentralized at same level of certainty. The inherent characteristics of blockchain architecture and design provide several properties that include privacy, security, and smart contracts (Christidis and Devetsikiotis, 2016). This paper focuses on blockchains, its characteristics in relation to sustainable supply chain visibility.

The remainder of this paper is structured into four sections. Section 2 explores the concept of visibility in sustainable supply chains. An overview of blockchains in sustainable supply chains is contained in Section 3. The characteristics of block chains and its relations to sustainable supply chain visibility is presented in Section 4. The paper ends in Section 5 with concluding remarks and recommendations for future work.

2. Sustainable Supply Chain Visibility

Visibility in the supply chain literature has been defined in a variety of ways, including, according to Barrat and Oke (2007), as 'the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit'. It involves ability to see clearly from one end of the supply chain to another, whilst sharing information on supply and demand issues across the chain. The primary antecedents of visibility are external and internal informational linkages and sharing of associated information (Barratt and Barratt, 2011).

Rungtusanatham et. al. (2003) introduced the concept of linkages in the supply chain, which they define as the 'explicit and/or implicit connections that a firm creates with critical entities of its supply chain in order to manage the flow and/or quality of inputs from suppliers into the firm and of outputs from the firm to customers.' An effective supply chain can result from such linkages with positive influence on operational performance for parties involved, if managed effectively (e.g Boyer et al., 2005), Information-based linkages can lead to sustainable competitive advantage (Rungtusanatham et al., 2003; Barratt and Oke, 2007). Barratt and Barratt (2011) found that individual internal linkages may be useful for extending externally derived visibility. They also noted that to extend visibility across the entire supply chain, organizations need to recognize the combining role of internal and external information-based linkages. The link between information sharing and visibility is established in the conceptualization of supply chain visibility by Barrat and Oke (2007). They posit that in the context of external supply chain linkages, certain organizational resources and capabilities enable information to be shared within the linkages which leads to improved visibility and subsequently improved performance. In this viewpoint, information sharing is an activity and visibility are a potential outcome of such activity (Barrat and Oke, 2007).

Sustainable supply chain visibility extends traditional supply chain visibility to encompass economic, environmental, social objectives of the supply chain. It is the extent to which actors within a supply chain have access to or share information (environmental, social and economic) which they consider as key or useful to their operations and which they consider will be of mutual benefit. Apeji et. al. (2017) identified four visibility impact areas and emerging themes regarding sustainable supply chain: a) realisation of quality information in supply chain ecosystems, b) advances in technology, tools, and the critical role of industry 4.0, c) reference models, architectures and frameworks, and d) creating integral value for stakeholders. Sustainable supply chain visibility can be facilitated through technological, non-technological, managerial, and organizational means. Enhancing sustainable supply chain visibility could act as a critical enabler for reducing supply chain risk, uncertainties, blue whip effect and offer an opportunity to improve the overall sustainability of the system.

3. Blockchains in Sustainable Supply Chains

A blockchain is a chain of blocks in which the blocks are digital pieces of information and the chain refers to its storage in a distributed database. The block stores information about a) transactions b) who is participating in transactions, and c) differentiation from other blocks. Blockchain provides an electronically decentralized and distributed public ledger for all participating actors implemented in a timestamped data structure. Blockchain contains nodes that groups the transactions into blocks. The nodes have responsibility for determining whether a transaction is valid and whether transactions should be kept in the blockchain. In tamperproof ledgers, transactions in blocks cannot be changed or deleted by a single actor.

Central to blockchain processes is security through cryptography and consensus mechanisms for verifying transactions (Swan, 2015) including ensuring immutability of the chain (Bashir, 2017). The consensus protocol is recognized as the core element of any Blockchain application and it is used for reaching consensus of information sharing, replicating state, and broadcasting transactions, among participating actors. There exist several consensus mechanisms (Mingxiao et al., 2017), and they include the Proof-of-work (PoW) and Proof-of-Stake (PoS) protocols. Other layers in blockchain architectures include governance protocols and smart contracts. A smart contract, featured in the application layer of blockchains, is responsible for monitoring, executing and enforcing a contractual agreement

There are many ways of categorising blockchain and they principally include public, private and federated, from the network's management and permissions viewpoint (Casino et. al., 2019). Public blockchains allows anyone to join as a new anonymous user and they can perform operations such as transactions or contracts or mining, permission less. Public blockchains are secured using a mixture of cryptographic verification and economic incentives, referred to as cryptoeconomics. In contrast, private and federated blockchains are categorised as permissioned blockchain in which specific users have permission over the network operations. In a private blockchain, only a specific organisation has the authority to join the blockchain network, carry out a new transaction, and contribute to the consensus mechanism. A federated blockchain is, in a sense, a mixture of public and private blockchains allowing for a partially decentralised design where leader nodes can grant permissions to other users. Federated blockchains are operated under a group of entities. In addition to the ownership and management of the information shared in the blockchain, other features such as transaction approval time and anonymity have also been studied in the literature (Casino et. al., 2019).

The blockchain is a driver of digital economy, a disruptive innovation which is attracting applications in a wide variety of domains including in sustainable supply chains. The main applications of blockchain technology in supply chain and logistics are increasing. In supply chains, blockchain solutions have been applied to improve cost, quality, speed, dependability, risk reduction, sustainability and flexibility with the incorporation of the Internet of Things (IoT) (Kshetri, 2018). Reported applications include: a) Korpela et al. (2017) on integration of Blockchain in supply chain management, b) Sheel and Nath (2019) on blockchain as a technology that can help improve supply chain adaptability, alignment, agility and performance, c) Tse et.al (2018) on blockchain technology in the food supply chain and highlights the benefits of seamless information exchange between partners and participants of the chain to achieve integrity, privacy, and trust, d) Feng et. al. (2020) on application of blockchain technology to improve agri-food traceability, and d) Mandolla et. al. (2019) on securing and organising the data generated through an end-to-end additive manufacturing process data in the aircraft industry.

There is evidence that blockchain can be exploited to build a secure and connected manufacturing infrastructure (Mandolla et. al. 2019). Feng et al., (2020) noted that integrating blockchain technology with IoT devices should help overcome information security and transparency concerns. Zelbst et. al. (2019) provide empirical evidence to support the implementation of a combination of RFID, IIoT and blockchain technologies as infrastructure necessary to achieve end-to-end supply chain transparency. They found that RFID technology directly and positively impact both IIoT and Blockchain technologies which, in turn, directly and positively impact supply chain transparency. Rogerson and Parry (2020) presented case studies in food supply chain to demonstrate that blockchain can be utilised as part of a system generating visibility and trust in supply chain.

The potential benefits of the blockchain-based supply chain management include informational security and accuracy, technological advantages, improvement of supply chain collaboration and trust, reducing economic loss and product waste, sustainability and transparency (Feng et. al., 2020). Blockchain technology is evolving and several challenges have been reported (e.g. Zheng et al., 2018). The challenges relate to scalability, security and stability requirements, design constraints and system performance, transaction capacity, and data accessibility. In addition, there are

challenges relating to blockchain infrastructure, interoperability and standardization, social and institutional that include legal and regulations issues.

4. Characterizing Blockchains and Sustainable Supply Chain Visibility

Blockchain systems and sustainable supply chain visibility are characterized by several factors. In what follows, the important characteristics of blockchain systems identified in the literature are highlighted and this is followed by a development of the characteristics of sustainable supply chain visibility. Finally, in this section, a perspective on the relation between blockchain characteristics and those of the supply chain visibility is presented.

A sample of the blockchain systems characteristics found in the literature is summarized in Table 1 below. The sample is from a range of perspectives in blockchain technologies. The blockchain characteristics highlighted are in aspects of Blockchain networks properties (Casino et al., 2019), improving agri-food traceability (Feng et. al., 2020), blockchain adoption challenges (Queiroz and Wamba, 2018), deployments, implementation, and properties (Viriyasitavat and Hoonsopon 2019), and blockchain critical success factors for sustainable supply chains (Yadav and Singh, 2020).

Table 1. Examples of Key Blockchain Characteristics found in the Literature

Casino et al. (2019)	Feng et. al. (2020)	Queiroz and Wamba (2018)	Viriyasitavat and Hoonsopon (2019)	Yadav and Singh (2020)
Consensus Mechanism	Decentralized and trustless network	Performance expectancy	Private, Public, and Permissioned Blockchain	System robustness
Identity Anonymity	Smart contracts in traceability business process	Social Influence	Centralization and Decentralization	Overall cost
Protocol Efficiency Consumption	Consensus mechanism	Facilitating conditions	Persistency	Overall performance
Immutability	Transaction transparency and anonymity of the traceability Chain	Blockchain transparency	Validity	Data safety and Decentralization
Ownership & Management	Data tamper-proof and traceable	Trust of supply chain stakeholders	Anonymity and Identity	Accessibility
Transaction Approval	High reliability of systems and data		Auditability	Laws and Policy
			Closedness and Openness	Smart system
				Customer satisfaction
				Reliable system
				Documentation
				Data management
				Quality

Table 2 is a consolidation of the key blockchain characteristics summarized in Table 1.

The most frequently mentioned characteristics in Table 1 are Anonymity and Identity, Consensus Mechanism, Decentralization, Overall Performance and Expectancy, Reliability of Systems and Data, and Transparency.

Table 2. Consolidated List of the Key Blockchain Characteristics

Accessibility	Overall Cost
Anonymity and Identity*	Overall Performance and Expectancy*
Auditability	Ownership & Management
Closedness and Openness	Persistency
Consensus Mechanism*	Private, Public, and Permissioned Blockchain
Customer Satisfaction	Quality
Data Management	Reliability of Systems and Data*
Data Safety	Robustness
Data Tamper-Proof	Smart contract & Smart Systems
Decentralization*	Social Influence
Documentation	Traceability
Efficiency	Transaction Approval
Facilitating Conditions	Transparency*
Immutability	Trust
Laws and Policy	Validity

Studies on characteristics of supply chain visibility reported in the literature has focused predominantly on information exchange and sharing competencies with some emphasis on the accessibility, quality, usefulness and adoption, and application of information. An effect of the relative improvement in the 'accessibility' and 'quality' of information sharing is improvement in business performance (i.e. stock reduction, delivery adherence, returns management, sustainability reporting etc.), facilitated by appropriate technology adoption.

Somapa et. al. (2017) provide insight into supply chain visibility characteristics and the related metrics. They reinforced the view that supply chain visibility characteristics can be captured in terms of the accessibility, quality, and usefulness of information. The main characteristics of supply chain visibility, as a basis for evaluating supply chain visibility effectiveness were presented to encompass automational charateristics, informational characteristics, transformational characteristics. The automational characteristics relate to timely use of information and communications technology in capturing and transferring of necessary information. The informational characteristics relate to managerial capability deployed to improve the quality of the exchanged information, and/or for channeling information flow. Finally, the transformational characteristics relate to aligning accessed information with the business processes and using the result to create business value through improvements in operational efficiency and strategic competencies.

In order to account for sustainability in metrics of supply chain visibility, Apeji et. al. (2019) turned to the notion of green absorptive capacity. Cohen and Levinthal (1990) first introduced absorptive capacity to an organisation context and it refers to an organisation's ability to recognise the value of new external information, absorb it, and apply it to commercial ends. Absorptive capacity is commonly described to consist of four processes of acquisition, assimilation, transformation and exploitation (Zahra and George, 2002). These processes are grouped into two higher order dimensions, namely, potential and realised absorptive capacity. An organisation's ability to comprehend, connect, combine, identify and apply environmental knowledge is referred to as green absorptive capacity (Chen et. al. 2014, Chen et. al. 2015). Dynamic capabilities are an organisation's ability to integrate, build, and reconfigure internal competences to address and/or make happen changes in the business environment (Teece, 2018). They are underpinned by organizational routines and managerial skills. Based on a dynamic capability view, supply chain capabilities are an organization's ability to identify, utilize, and assimilate both internal and external resources/information to facilitate the entire supply chain activities.

Context is also important in the characterization of sustainable supply chain visibility as the level of visibility can be impacted by the context and sector to which it has been applied. For example, visibility in the context of humanitarian organisation is a complex issue to maintain and there is the added challenge of the temporary status of relief operations (Maghsoudi and Pazirandeh, 2016). The information shared in supply chains should not only be complete, objective and accurate, it should also be in the right context for it to be effectively used (Ryu et. al., 2009) A way to conceptualise visibility is as an alignment of viewpoints, context, purpose and actions through information sharing and collective learning to arrive at a shared goal (Maghsoudi and Pazirandeh, 2016).

To apply blockchain into processes for sustainable supply chain visibility efficiently, blockchain and sustainable supply chain visibility characteristics must be identified. Blockchain and its characteristics can improve sustainable supply visibility. In this paper, the characteristics are conceptualized into two main categories – foundational and applicational. The foundational category denotes the underlying basis or principle of blockchains, essentially the core elements upon which blockchains are built e.g. consensus. The applicational category represents blockchain characteristics, beyond the foundational, that are relevant to supporting an application and putting the application into operation such as those required for sustainable supply chain visibility platforms.

The most frequently mentioned blockchain characteristics highlighted in Table 2 above, that is, Anonymity and Identity, Consensus Mechanism, Decentralization, Overall Performance and Expectancy, Reliability of Systems and Data, and Transparency are relevant to sustainable supply chains and are a mix of foundational and applicational characteristics Some additional blockchain characteristics in relation to sustainable supply chain visibility characteristics identified are also needed to better support information-based linkages, alignment of viewpoints and relationships, green absorptive capacity, green dynamic capabilities and information sharing. From a dynamic capabilities perspective, Lambourdiere and Corbin (2020) propose for maritime operations that blockchain technology can increase the value of the capability of supply chain visibility for a firm. Applying block chain characterises to improve the supply chain capabilities of information sharing, coordination and visibility is important.

The blockchain characteristics of accessibility, quality, transparency, trust, traceability, smart contract and decentralisation also make the blockchain technology attractive for supply chain visibility, predominantly from an applicational characteristics viewpoint This is particularly in support of the automational (the ability to access information) and informational (the quality of the information) characteristics of supply chain visibility. Blockchain technology makes information sharing easier, facilitates real-time analysis and enables two or more actors to work simultaneously on the same kind of information. Hence, resulting in a better prospect for the transformational (the utilization of information) characteristics of sustainable supply chain visibility.

Blockchain, through its trust characteristics, does not allow issues around trust to come in the way of information sharing. The blockchain technology enables sustainable supply chain focal company, its external and internal linkages to collaborate effectively by sharing useful information they have in the blockchain. Increasing paradigm shift towards transparency between firms and stakeholders within their supply chain offers another important relation between sustainable supply chain characteristics and blockchain characteristics. The choice of Private, Public, and Permissioned Blockchain characteristics is a significant consideration for sustainable supply chain visibility applications. Using a completely public or a completely private ledger architecture for information exchange may fail to address the requirements of various applications including supply chain visibility applications (Wu et. al., 2017).

Sustainable supply chains that adopt blockchains, leveraging its foundational and applicational characteristics, can turn challenges into opportunities that would help improve the relationship with the various stakeholders thereby enhancing the reputation of their supply chain and the ensuing visibility. This improves the social awareness of the stakeholders and facilitates effective engagement with stakeholders in support of the transformational characteristics of the chain's visibility; the facilitating conditions and social influence aspect of blockchain adoptions can play a part. Integration of digital technologies such as RFID, internet of things, and big data with blockchain technology is also important and this can be further enabled through related blockchain characteristics.

5. Conclusions and Future Work

Blockchain has induced a growth in research interest in the technology and in industry applications; the resulting advances is pushing the boundaries, including in the field of sustainable supply chains. Establishing the characteristics of blockchains, in terms of foundational and applicational characteristics, that relate to sustainable supply chain visibility is beneficial. Through an understanding of the relation, relevant blockchain architectures and applications

can for example be developed for sustainable supply chain visibility. This study posits that the key characteristics of blockchain technology are related to identified characteristics of sustainable supply chain visibility particularly in terms of developing trusted linkages, alignment of viewpoints and relationships, support for green absorptive capacity, green dynamic capability, and information sharing. Future work could involve an empirical validation of the interrelationship of blockchain characteristics with respect to sustainable supply chain visibility and development of an architecture based on the key characteristics.

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