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Blockchain Technology and Green Supply Chain Management (GSCM) – Improving Environmental and Energy Performance in Multi-echelon Supply Chains

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Abstract: In this competitive and technology driven world, businesses are striving to gain benefits of environmental sustainability and energy conservation by implementing the latest technologies in their supply chains. A promising way of evaluating the environmental performance of a product or a process is Life Cycle Assessment (LCA) modelling, but the reliability of LCA results is mostly compromised due to the lack of real data from upstream and downstream supply chains. Our research aim is to drive LCA modelling through Blockchain Technology (BCT) and internet-of-things which have the capability to record reliable, transparent, and secure data from across the supply chain. The modified LCA model will provide various industries with the quantified benefits of BCT in terms of industrial emissions reduction. This conference paper reflects the 1st stage of research where we carried out a detailed literature review on potential use of blockchain technology in green supply chain management and based on the findings, we developed an integrative framework architecture for the supply chain of a supermarket product. In the next phase, the integration of BCT and LCA will be studied in food supply chains using a supermarket case study of Walmart-IBM developed blockchain consortium.

1. Introduction

Major climate change databases like the Carbon Disclosure Project (CDP) and Global Reporting Initiative (GRI) have been reporting lack of scope 3 emission disclosures by Multinational Corporations (MNCs). The underlying reason is the limited control and access to foreign supplier's emission data by these large companies. United Nations (UN) has also criticized these corporations and encouraged researchers to develop mechanisms to precisely record emissions from upstream and downstream supply chains to eliminate discrepancies in data sharing and information flow.

Supply chain complexity has been continuously increasing over the last decade as the demand of products is increasing. Resultantly, this increases the number of globally dispersed entities in supply chains, geographically distant production lines, critical international and local regulations, and customer/investor pressure on sustainable management of complex supply chains. Therefore, due to this complex environment consisting of multiple players, varying regulations and diverse cultural behaviour, risks can be encountered in supply chain networks [1-4]. With the latest emerging trends in technology adoption and development of Industry 4.0, it is critical to investigate these technologies in various supply chain business models. In the last decade, many new technologies have emerged, and the field of IT has flourished across the globe providing sustainable solution to many of the real-world problems. Recently developed technologies like Artificial Intelligence (AI), cloud computing, 5G/6G networking, Internet of Things (IoT), blockchain, robotics, and drones have found their applications in many business processes [5].

While we have discussed the increasing complexity of supply chains, understanding the risks and consequences of running multi-echelon system is also important. Ineffective verbal dealings, information mismanagement, record tampering, and poor coordination leads to uncertainties and an increase in pain points of such supply chains. To prevent these issues, new technologies are being designed to overcome these issues. One such technology is Blockchain Technology (BCT), which transforms manual business dealings into automated contracts, records and shares the source information among all the supply chain members. It also decentralizes the whole supply chain network to eliminate the interference caused by central entities in distributed ledgers [6].

Blockchain Technology (BCT) can be defined as a distributed ledger or distributed database of records for all the transactions or digital events taking place in a peer-to-peer network [5, 7]. The network members, also known as nodes, can store, validate and access the data following a protocol called smart contracts. In a multi-echelon supply chain environment, if a member or node carries out a transaction or the product is leaving their facility, then they can record the important information about the nature, quality, quantity, location and ownership of product using blockchain. Each transaction of record is encrypted by a timestamp which indicates the occurrence of an event or addition of a new transaction. Once the information is recorded, it is verified and digitally signed by the involved parties making it secure and immutable. Copies of these records are distributed among all the interlinked parties as well as the miners, who are responsible for verifying the credibility of information source. After validation of the transaction by a miner, the miners receive the cryptographic reward, mostly in the form of digital currency. The transaction then gets included in the distributed ledger along with the digital signature and time stamp for the identification of responsible party [8].

In supply chains, we have seen a dramatic increase in the use of RFID, sensors and actuators and how they automate the process of product movement in warehousing, transportation and consumer market [9]. Hence, BCT can be integrated into this architecture to store and encrypt the product information monitored by the IoT devices, making the IoT platforms more useful and secure while reducing the traditional costs of using centralized approaches [10]. Furthermore, a peer-to-peer enabled blockchain will enhance the security and reliability of sensory networks and devices, making these devices more popular and providing the IoTs with a higher level of control in supply chain systems [11, 12].

In our previous research publication [13], we reviewed the literature on Green Supply Chain Management (GSCM) and developed a state-of-the-art supply chain model for the integration of green practices and technologies in the value chain of the firms. The results of that study indicated the need for transparent collaboration methods and innovative technologies to successfully record and improve the suppliers' emission levels. Blockchain Technology (BCT) is one such innovative solution, which consists of sequence of blocks on a cloud platform, carrying authenticated information in a decentralized manner. Therefore, BCT has the ability to record emissions data from all tiers of supply chain including the probed scope 3 emissions while maintaining the reliability, transparency, and data security. The integration of BCT in green supply chains and potential benefits are being studied in this research and conventional Life Cycle Assessment (LCA) method is analysed to assess the improvement in LCA results upon switching to blockchain based data collection. Finally, a supply chain model of a supermarket food product is prepared integrating BCT, IoT and smart contracts to address the ingredient provenance and data availability issues in food supply chains.

The results of our study will provide the food industries with a road map to establish a blockchain based green supply chain model to accurately measure their product/process emissions, helping them in meeting their Sustainable Development Goals (SDGs). This research also inclines to develop a durable way to assess the emissions of foreign suppliers and managing their performance can be made simpler through implementation of blockchain technology. Emissions data from every member of supply chain will be encrypted in to blocks that are accessible by all the members and cannot be manipulated. Implementation of BCT can benefit the environment and the MNCs by tracking the green products, reducing energy usage throughout the supply chain, encrypting carbon footprint of each member, assisting in recycling, and improving Emission Trading System (ETS). The rest of the

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paper begins with section 2 on literature review after which blockchain based supply chain framework is presented in section 3 following the discussion on LCA and BCT integration capabilities in section 4 and finally, section 5 presents the conclusion.

2. Literature review

Blockchain as a distributed ledger can be distinguished from other distributed ledger systems as it provides the freedom to decentralize information handling. Therefore, as per rights of the user, blockchain can take form of either centralized or decentralized ledger. In case of centralized ledger, a single primary party carry out the decision-making process, whereas, in decentralized ledger, multiple parties share the process of decision-making [5]. However, the flow of information and its credibility is not compromised in both cases as each block of transaction is connected to the previous block using complicated hash algorithms which eliminates the possibility of cyber-attacks and internal system breaches [11]. These connected blocks solve the issue of traceability and each network node can access the transaction or product history they require using their digital key [14, 15]. In a nutshell, a transaction block is formed after the miners and nodes validate a transaction and each block is connected to previous block taking form of a blockchain which resolves the issue of transparency, security, traceability and reliability within the involved parties.

Blockchain technology has the capability to transform the conventional supply chain transactions in to more secure, legit and digitally regulated and encrypted blocks with minimum risk of data tempering. Manupati, Schoenherr [16] developed a “consortium blockchain” framework for multi-echelon supply chain network. A consortium blockchain is defined as a semi-private blockchain network managed by multiple participants of supply chain working together on a common platform [16]. The complete environment is isolated from external threats as all the transaction data is secured within the consortium framework. To facilitate the implementation of BCT in green supply chain management, specialised smart contracts can be generated to enforce the set rules and codes of practice. These smart contracts automatically check the new transaction against the set rules and all supply chain participants abide by the smart contractual agreements [9]. For instance, smart contract can contain the threshold limits for the emissions or other product quality determinants and if a transaction has crossed the limit, the smart contract will flag the transaction and notify the responsible parties of the breach. The supply chain managers can easily identify the pain points and alter the system to resolve the issues relating emissions and product quality. Therefore, through blockchain technology, the trust is shifted from human agents to the computer codes and smart contracts for the verification of transactions [9, 17].

Although the BCT has emerged under the umbrella of bitcoin and other cryptocurrencies, its applications in other industries are also being studied [18]. Around the globe, the financial institutions are exploring BCT to transform the capital market and the financial operations within the market [19]. Under the domain of financial institutions, BCT has provided many operational benefits in financial auditing, digital payments, financial loan schemes, derivative transactions and cryptocurrency exchange [20-22]. BCT has also recently been investigated in insurance market for assisting in multiple areas including claims processing, customer sign-ups, reinsurance and general sales [23]. BCT has also found vast application in city governance and policy making due to its potential of overpassing the corruption and other illegal acts. Ibba, Pinna [24] and Sharma, Moon [25] studied BCT in context of smart cities and provided empirical evidence of its potential benefits in integrating physical, environmental, social and business infrastructures for managing smart cities. BCT can also be used in public services for the purpose of citizen registration, attestations, marriage registrations, patent management, elections and income taxation systems [4]. Figure 1 shows a cluster of BCT applications in different sectors including the energy optimisation and supply chain management.

Figure 1. Cluster of BCT applications[4]

Applications of BCT in energy sector have been researched enormously during the last decade, mainly due to the improved process and cost capabilities [26]. The myriad of benefits that BCT brings into the energy sector include enabling new business marketplaces, reducing energy complexity, reducing the costs, and enhancing the trust in energy markets [17]. The critical tracing capability of BCT framework can help in promoting green energy by issuing certificates based on origin of the energy and by developing business-to-business energy transaction schemes such as Emission Trading System (ETS) and carbon taxation [27-29]. While all the efforts of world economic and energy bodies are towards energy resilience and green energy transformation, BCT has raised the hopes by decarbonising the energy sector through development of more decentralised energy distribution frameworks [4]. Like energy sector, research on BCT has also showcased its potential in improving healthcare management systems like Electronic Medical Records (EMRs) applications that the hospitals and practices rely on for their day-to-day operations management including recording patients data, taken procedures, existing medical conditions, medical tests conducted and appointment bookings [30].

Use of a series of interconnected sensors is common in supply chains and despite its drawbacks in terms of sensor tempering and centralized architecture, IoT is still considered a revolutionary technology changing the shape of conventional supply chains [31, 32]. With the increasing research in decentralizing the IoT platforms and their security enhancement, its integration with BCT was researched further to explore the promising solution that BCT can bring to the conventional architectures of IoT devices [33]. Many authors have researched on the symbiotic relationship between

Internet of Things (IoT) and BCT. For instance, the distributed wireless sensor network has its limitations in terms of real-time monitoring, centralized nature of platform, tampered sensory architecture and inefficient data encryption through the sensors [9]. Integration of BCT to IoT can enhance the auditability and security of data exchange in heterogeneous environment of large number of interconnected smart devices [32].

It has also been demonstrated in multiple studies that blockchain-based supply chains have less disputed parties and better contract management systems for third and fourth party logistics (3PL, 4PL) reducing the information asymmetries [14, 34]. Such supply chains when powered by the tracking capabilities of BCT can improve the inventory management system in complex supply chains by optimising the smart transportation systems decentralised production architectures [35, 36].

2.1 Blockchain technology and green supply chain management

In recent years, researchers have initiated the implication studies of BCT in the context of green supply chain management. Zhao, Liu [37] initiated the research on BCT applications in sustainable water management and presented the challenges and future research potential of BCT in sustainable supply chains. Following this study, researchers started critically analysing the opportunities and challenges of BCT in agricultural supply chains [16, 38, 39].

Among all the supply chain sectors, BCT has gained most importance in food supply chains due to the risks and challenges posed in the food supply chains [40]. Involvement of multiple entities and suppliers from across the globe providing raw materials and other resources is a major challenge as reliability of information and data from these suppliers is very low and usually the underlying reasons are disclosed mainly after the major loss or repeatedly reported food diseases [37]. The study of Lau, Shum [41] analysed various methods to enhance the authenticity of organic food suppliers using a game theoretic approach and suggested the need to implement latest tracing methods at the facilities and farms of the international suppliers. Figure 2 demonstrates a basic agricultural transaction recorded through BCT. It involves the selling of wheat from party A to party B.

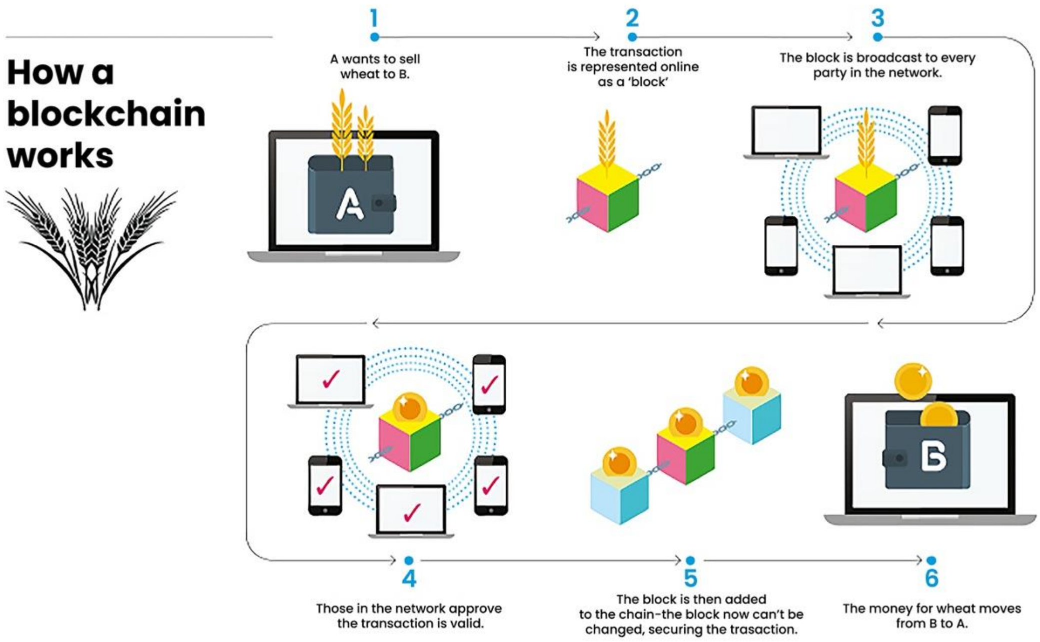

Figure 2. Blockchain based agricultural transaction (source: www.nswfarmers.org.au)

BCT application in green supply chain management has the potential to track substandard products accurately and ceasing further transactions of such product that saves the business from recalls, resource consumption and untraded GHG emissions [42]. In conventional supply chains, it's a challenge to evaluate carbon footprints but blockchain enabled supply chains can reduce the emissions during the product manufacturing journey by maintaining the manufacturing standards through smart contracts and applying low carbon product designs during production and transportation stages [43]. Other green benefits of BCT includes assisting in recycling by using cryptographic rewards for sustainable disposal at the end-of-life of products. It is also beneficial in improving the carbon taxation and Emission Trading Schemes (ETS) where the carbon trade will be based on blockchain data free from discrepancies [44].

3. Framework Development – Blockchain Based Food Supply Chain Model

In a multi-echelon supply chain environment, such as supermarket food products, whenever a member of the supply chain layer carries out a transaction or the product is leaving their facility, IoT devices (digital layer) record important information about the nature, quality, quantity, location and ownership of the product (see Figure 7). This information is then added to the blockchain, encrypted by a timestamp which indicates the occurrence of an event or addition of a new transaction to all the entities. Once the information is recorded, it is verified against the smart contract and digitally signed by the involved parties making it secure and immutable [8]. Figure 3 is designed to illustrate the transformation of conventional supply chain in to IoT-BCT powered supply chain architecture.

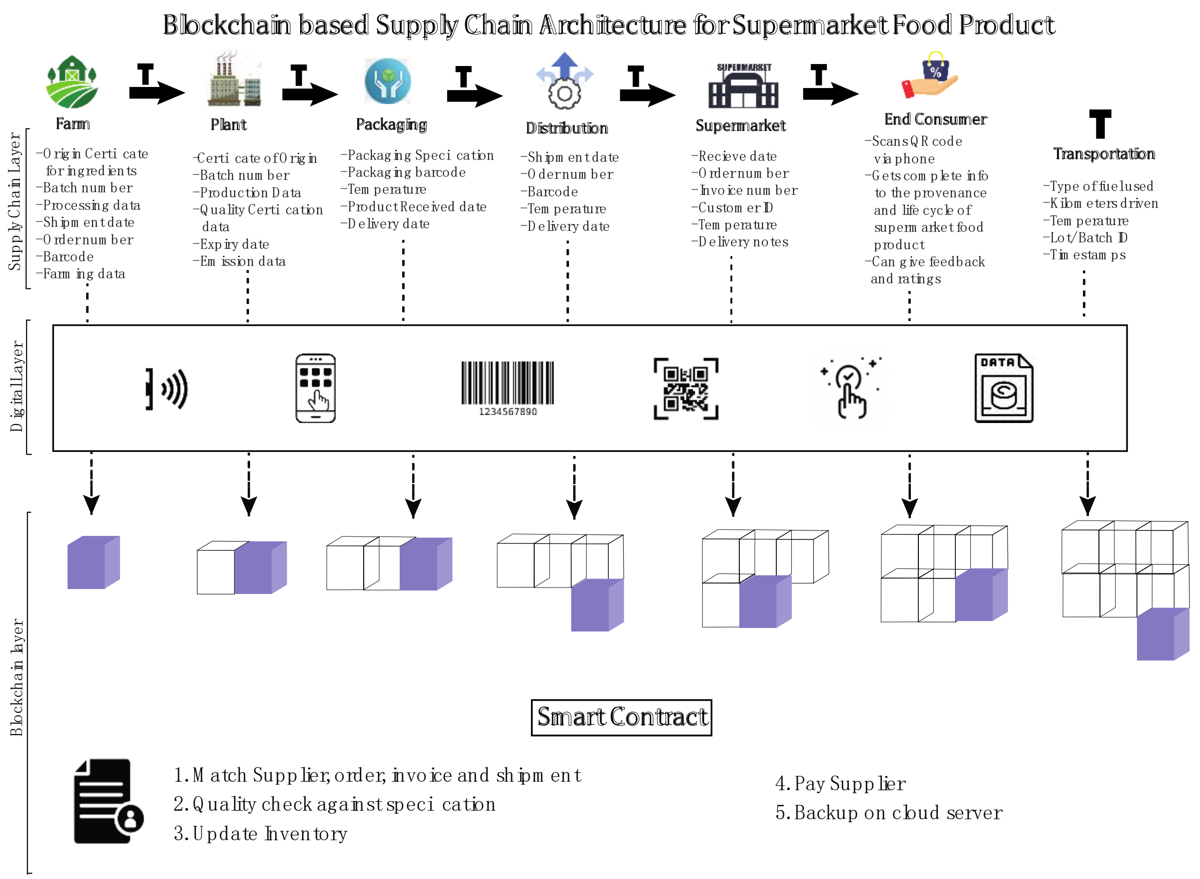

Figure 3. A blockchain based architecture for the supply chain of supermarket food

To facilitate the implementation of BCT in green supply chain management, specialized smart contracts can be generated to enforce the set rules and codes of practice. These smart contracts automatically check the new transaction against the set rules and all supply chain participants abide by the smart contractual agreements [39]. Such smart contracts have to be completely integrated into firm's ERP system to overcome any compatibility issues [45]. For instance, smart contract can contain the threshold limits for the emissions or other product quality determinants and if a transaction has violated the limit, smart contract will flag the transaction and notify the responsible parties of the breach. Therefore, supply chain managers can easily identify pain points and alter the system to resolve the issues relating emissions and product quality. Therefore, through blockchain technology, the trust is shifted from human agents to the computer codes and smart contracts for the verification of transactions.

3.1 Life Cycle Assessment (LCA) and blockchain technology

This research has encompassed the method of Life Cycle Assessment (LCA) as it is widely used to determine the effect of new technologies and practices on the environment. Successful LCA requires reliable input data that will be processed to determine the environmental damage from a product or process. With LCA, we can evaluate and compare environmental footprints upon switching to blockchain enabled supply chain data collection. We have used hypothetical case of a supermarket product to develop the BCT enabled supply chain model and for the empirical evidence, we tend to develop a LCA framework powered by blockchain based data. For this conference proceeding, we only analyse the feasibility of BCT and LCA integration and in the next phase of research, we will present an integrative LCA framework and using SimaPro LCA software, we will determine the change in environmental footprints driven by the implementation of BCT in supply chain.

Mainly two types of data are used to carry out the LCA modelling efficiently, foreground and background data. Foreground data is the product-level data whereas background data consists of across the supply chain data including external resources, transportation and waste management data [42]. The quality of data is critical as it can change the results of LCA and can underestimate the severity of environmental damage, especially in case of new products [46]. LCA is carried out in four stages: (1) defining goal and scope of LCA, (2) Life Cycle Inventory Analysis, (3) Life Cycle Impact Assessment, and (4) Life Cycle Interpretations. Integration of BCT and LCA will mainly improve stage 2 and 3 of LCA as these stages incorporate the external data for computations and determine the impact of a product on the environment.

During the second stage of LCA, Life Cycle Inventory (LCI) analysis, all inputs and outputs of functional unit are quantified, and data for all the inputs and outputs of functional unit is noted. The LCA practitioners has found it to be the most challenging stage of LCA as all input data is not available for complex supply chains and much of the data is supposed which risks the reliability of LCA modelling [47]. So, BCT will be a helpful tool for this stage as data powered by these technologies is easily traceable, highly transparent, and reliable. Moreover, the automatic fetching of data with IoT and its real-time availability to all the supply chain members through BCT makes it more promising as the real-time and secure data will fortify the required outcomes from LCA modelling [42].

The third stage called as Life Cycle Impact Assessment (LCIA) involves the thorough evaluation of the functional unit in terms of its impact across various impact categories including climate change, Global Warming Potential (GWP) and soil acidification. With the integration of BCT and IoT, impact assessment will be significantly improved, and many useful and true insights can be explored during this stage. IoT devices such as sensors and actuators have the capacity to continuously record data transactions which can form big data and using big data analytics, researchers cannot only improve their LCA results, but can also improve the upcoming products during their design stage to further save the environment.

Future directions from Zhang, Zhong [42] suggests the development of proof-of-concept Blockchain based LCA model and also find out the barriers in the integration of LCA and BCT. Zhang, Zhong [42] has made the first attempt to integrate BCT with LCA and presented a system architecture of BCT-LCA for improved environmental performance. But due to the initial state of this research area, authors did not present industry specific integration and insights on the improvements achieved through the integration of these technologies. We are taking the research on the integration of BCT, IoT and LCA to its next step to determine its implications in food supply chain.

4. Conclusion

With food consciousness growing globally, and food retailer's becoming increasingly concerned about the impact of their extended supply chains, it is important to research the latest technologies and their potential to reduce supply chain uncertainties. This research has incorporated blockchain technology to assess the critical scope 3 emissions' issue in food supply chains. Our study has analysed the smart contract based BCT architecture and integrated it with the digital platforms, such as Internet-of-things and RFIDs, that have the capability to fetch immutable data directly from the supply chain. This factual data can be used in Life Cycle Assessments (LCAs) of food products since the data scrutiny in LCA modelling has been greatly criticized in literature and our proposed mechanism of blockchain integrated LCAs can improve environmental footprint evaluations by using real and immutable data. In next stages of our research, we are conducting a blockchain driven LCA of a food product and comparing the environmental footprints against conventional LCA results. The research outputs are critical to the food industries as it provides improved environmental evaluation method and empirical framework to adopt BCT in their supply chains. In future, this research can be extended to real-world food products by gathering primary data directly from food industries and using it in LCA to evaluate environmental footprints from different segments of the products' supply chains.

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