sustainability

Review

The Effect of Blockchain Technology on Supply Chain Sustainability Performances

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Abstract: Improving supply chain sustainability is an essential part of achieving the UN's sustainable goals. Digitalization, such as blockchain technology, shows the potential to reshape supply chain management. Using distributed ledger technology, the blockchain platform provides a digital system and database to record the transactions along the supply chain. This decentralized database of transactions brings transparency, reliability, traceability, and efficiency to the supply chain management. This paper focuses on such novel blockchain-based supply chain management and its sustainability performances in the areas of environmental protection, social equity, and governance efficiency. Using a systematic literature review and two case studies, we evaluate whether the three sustainability indicators can be improved indirectly along supply chains based on blockchain technology. Our study shows that blockchain technology has the potential to improve supply chain sustainability performance, and we expect blockchain technology to rise in popularity in supply chain management.

Keywords: blockchain; supply chain; sustainability; IBM food trust; TradeLens

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1. Introduction

The COVID-19 pandemic has revealed a general lack of visibility and data exchange with global supply chains [1]. In an attempt to build resilient supply chain management, blockchain technology has become a prominent tool, which is a novel technology using distributed and decentralized ledger to trace the real-time movement of goods and services in a supply chain, thus bringing transparent and robust connectivity in the process. Blockchain technology has seen an extensive application among businesses, such as financial services (e.g., Ripple and Libra), food and agricultural distributions (e.g., IBM Food Trust and Bumble Bee Foods), and healthcare and pharmaceutical supply chains (e.g., ProCredEx and MediLedger). There is a general consensus about the value of the blockchain to achieve a reliable supply chain system. Among many others, one major contribution is its potential to promote sustainable development. Our project will focus on the blockchain-based supply chain and evaluate its unique contributions to the three pillars of sustainability—environmental protection, social equity, and governance efficiency.

A central focus of the literature has been conceptualizing the impact of blockchain technology on supply chain management. For example, Saberi et al. [2] introduced several blockchain technology adoption barriers in supply chain and described how it could affect local and global supply chain sustainability. We argue that there are two fundamental reasons why focusing on sustainability is important: First, the role of supply chains for a sustainable global economy has become increasingly prominent in recent years. Over 93 percent of the world's 250 largest firms report on sustainability. Therefore, sustainability in the supply chain will be imperative. Second, as blockchain technology becomes increasingly popular, it is important to document its role in various aspects, such as promoting sustainability. Accordingly, this paper explores the effects of blockchain technology on sustainability performance in supply chain management. It analyzes critical sustainability measurements that can be considered to quantify corporate performance through an extensive literature review. The purpose of this study is to document the association of blockchain technology and the three pillars of sustainability, environmental (e.g., waste management), social (e.g., public perception), and governance (e.g., corporate management). To this end, we also provide two case studies showing the contribution of blockchain technology to sustainability in the context of the food supply chain and logistics (the three pillars of sustainability follow the United Nation's Sustainable Development Goals (SDG)).

We propose a two-step framework. First, following a systematic literature analysis approach, we conduct a broad review of the previous studies regarding the association between the blockchain-based supply chain and sustainable development. We collect the most relevant articles on our topic by searching for the proper keywords. Our proposed analysis includes four research focuses: (i) blockchain technology in supply chains; (ii) blockchain-based supply chains and environmental sustainability; (iii) blockchain-based supply chains and social sustainability; and (iv) blockchain-based supply chains and economic (governance) sustainability.

Having documented these associations, in the second step, we provide two case studies regarding the blockchain-based system and sustainability. The first case study is focused on the collaboration between Wal-Mart and IBM Food Trust. The IBM Food Trust program applies blockchain technology to food supply chains to enhance food safety and security. It aims to reduce tracking time, shorten operation process, result in a reduction in truck gas consumption, and ultimately make resource planning more efficient. The second case study explores the Maersk blockchain-based system in logistics. Their blockchain system is in its infancy. Therefore, we analyze the potential effect on their sustainability performance based on the literature reviews and the company's sustainable report, given they do not have direct evidence of sustainability performances. Our paper aims to shed light on two issues through case study analysis: First, what is the overall relationship between blockchain technology in the supply chain and sustainability performance? Second, the effectiveness of blockchain technology on supply chains' sustainability performance. Our study extends the literature by analyzing the effects of blockchain on the supply chain, emphasizing the sustainability concept. This suggests directions for a future research agenda that will further quantify sustainability performance.

Our paper proceeds as follows. Section 2 summarizes the background of blockchain technology and the blockchain-based supply chain. In Section 3, we introduce the Systematic Literature Analysis method and use it to select a list of articles for later analysis. Using the method in Section 3, we present in Section 4 the concepts of sustainability and how the blockchain-based supply chain contributes to its performance. In Section 5, we present two case studies on Wal-Mart's collaboration with the IBM Food Trust Program in the food supply chain and Maersk with IBM in the shipping industry. We conclude our paper with future directions in Section 6.

2. Blockchain-Based Supply Chain

Blockchain refers to a technology that stores and distributes data based on databases among all users who are stakeholders participating in the network [3]. All participants can access detailed transaction information in real-time. In the past, transaction data were stored in a centralized hub system and shared information with direct transaction participants. However, blockchain technology enables people to share all information based on decentralization, security, and smart execution. In other words, all participants can access to transaction details one after another through peer-to-peer networks (refers to decentralization) [4,5]. Moreover, if transactions are performed by signatures, security is enhanced, and ultimately, transparency is secured. Therefore, if any operational problems occur, they can be cooperatively processed promptly (security) [4,6]. Additionally, once a transaction is recorded in the system with a validated signature given to the users, it remains unchanged. This feature is called "immutability" [7]. Given all these features, this technology is expected to bring benefits to many industries. It greatly influences the supply chains, where information sharing is a key aspect [8,9]. This study explores how blockchain technology impacts supply chain management.

Supply chain management is a process that encompasses the entire process of transporting, storing, and delivering products from the place of raw materials to production and to the final consumers [10]. Blockchain technology is expected to bring various advantages to supply chains, including increasing efficiency and lowering costs, which are the two main objectives of the supply chains. Meantime, the literature on blockchain-based supply chains is growing [11]. Below, we summarize the four characteristics of blockchain-based supply chains: traceability (or visibility), reliability with security, synchronized transaction process, and cost efficiency [7,8].

2.1. Traceability (or Visibility)

Within the blockchain-based supply chain environment, real-time location tracking of goods becomes easy. Traceability is defined as the ability to trace all information in real-time [9]. For instance, container freight management and document processing regarding transactions can be stored and shared in the blockchain. All transaction information can be confirmed by relevant participants along the movement path of cargo in real-time through blockchain technology [12]. Therefore, a blockchain-based supply chain allows for enhancing transparency [2].

2.2. Reliability and Security

It is known that the blockchain system helps to reduce the risk of counterfeit or unlicensed products distributed in the region. This is because blockchain is a decentralized record-keeping system [8,9]. Many industries, such as the food industry, employ this function to their supply chains based on blockchain technology [13,14]. Particularly, blockchain technology can manage inventory appropriately while tracking cargo and recording and managing cargo history. This makes it possible for consumers to trust the product, because anyone who participates in the transaction can share and verify all the information. Based on these primary functions, supply chain processes and objectives are impacted positively. This study sheds light on two advantages of blockchain-based supply chains: synchronized transaction process [15] and cost efficiency [4,16].

2.3. Synchronized Transaction Process

The contract process of supply chains is simplified on account of blockchain technology. In the past, the contract between the seller and the buyer took a complicated procedure [17]. Blockchain eliminates unnecessary and complicated documents through a smart contract. A smart contract refers to a transaction protocol supporting the automated execution and control of documents [7]. This system makes a simplified process that all relevant parties are necessary to check the agreement through digitally signed documents within the blockchain system [12].

2.4. Cost Efficiency

Supply chains are associated with many relevant costs, such as inventory and transportation, affecting the total cost [18]. Blockchain-based supply chains allow us to manage inventory efficiently and help to reduce costs [4,16]. Logistics covers all processes from the point of departure to the end destination, so unnecessary losses are profits. In particular, inventory accounts for the most significant cost, and the supplier needs to periodically forecast demand to produce and purchase inventory in a timely manner [19]. If the company has excess inventory than demand, the economic burden will increase with stock-out costs. When operations manage fewer inventories, paying lost sales costs is required [14]. Therefore, the blockchain-based supply chain enhances cost efficiency through traceability and security functions [9].

3. Methodology: Systematic Literature Analysis

This study explores the literature of the blockchain-based supply chain with the sustainability concept by employing systematic literature analysis methods. This method can reduce any potential biases by examining the detailed contents [20]. Simply put, we performed two steps: collecting articles by searching for a list of specific keywords, and then examining the trend in these articles. We only considered the literature after 2017, because blockchain technology has only been adopted since 2017 in supply chain management.

We first collected the most relevant studies by conducting keyword searching in Google Scholar database. The final list of primary keywords included "blockchain", "supply chain management", "Blockchain-based supply chain", "sustainable supply chain", "sustainability" and "blockchain sustainable supply chains". We considered peer-reviewed journal articles, academic books, and business-related news articles through Google Scholar (www.scholar.google.com (accessed on 4 February 2021)) and the Web of Sciences from 2017 to 2021. As a result, we refined a total of 23 references.

Table 1 indicates a literature summary of these 23 references. As it shows, the most common keywords are "blockchain technology" and "supply chain management". The most-cited two articles (number 8 and 11) share three keywords: "blockchain technology", "supply chain management" and "sustainability". Previous studies examine how the blockchain-based supply chain influences sustainability with discussion through the case studies or literature reviews of the technology-based supply chain with sustainability [5,21–26]. Saberi et al. [2] investigate the benefits of sustainability by adopting blockchain technology in supply chains. Moreover, several papers have discussed the three pillars of sustainability with the blockchain supply chain. First, environmental sustainability enhancement was discussed [2,24,27–32]. Moreover, several papers explore social sustainability issues [2,24,29,31–38] and economic (or governance) sustainability issues [2,31,32,38–40]. Detailed descriptions of the potential indicators of the three pillars of sustainability with blockchain-based supply chains in the literature review can be found in the next section.

Table 1. Literature summary (accessed in August 2020).

No	Author	Year	Keywords	Journal	Google Scholar Citations
1	Cartier et al.	2018	No Keywords	Journal of Gemmology	15
2	Chang	2019	No Keywords	Rutgers University, Doctoral Dissertation	0
3	Cole et al.	2019	Blockchain Technology; Research Agenda; Operations and Supply Chain Management	Supply Chain Management: An International Journal	52
4	Hastig and Sodhi	2020	Supply Chain Traceability Systems; Blockchain; Thematic Analysis; Stakeholders; Business Requirements; Critical Success Factors	Production and Operations Management	13
5	Helo and Hao	2019	Blockchain; Distributed Ledger; Operations; Supply Chain; Logistics	Computers and Industrial Engineering	34
6	Hughes et al.	2019	Barriers; Blockchain; Information Systems; Literature Review; Opportunities; Sustainable Development Goals (UNSDGs)	International Journal of Information Management	103
7	Li et al.	2020	Production Capability Evaluation; Supply Chain Network; Blockchain; IoT; Machine Learning	International Journal of Production Research	3

Table 1. *Cont.*

No	Author	Year	Keywords	Journal	Google Scholar Citations
8	Saberi et al.	2019	Blockchain Technology; Supply Chain Management; Sustainability; Barriers; Research Agenda	International Journal of Production Research	304
9	Di Vaio and Varriale	2020	Blockchain Technology; Operations Management; Supply Chain Management; Sustainable Performance; Airport Industry; Non-Financial Reports	International Journal of Information Management	16
10	Casey and Wong	2017	No Keywords	Harvard Business Review	126
11	Kshetir	2018	Auditability; Blockchain; IoT; Network Effects; Supply Chain; Sustainability	International Journal of Information Management	428
12	Kouhizadeh and Sarkis	2018	Blockchain; Supply Chain; Green Supply Chain; Use Cases; Applications	Sustainability	79
13	Nikolakis et al.	2018	Blockchain; Value Chain; Governance; Sustainability; Smart Contracts	Sustainability	24
14	Treiblmaier	2019	Blockchain; Distributed Ledger Technology; Physical Internet; Logistics; Supply Chain Management; Research Framework; Innovation; Information Technology; Triple Bottom Line; Sustainability	Logistics	16
15	Nayak and Dhaigude	2019	Supply Chain Management; Small and Medium Enterprises; Technology Adoption; Multicriteria Decision Making; Sustainability	Cogent Economics and Finance	1
16	Son-Turan	2019	No Keywords	Blockchain Economics and Financial Market Innovation (Book chapter)	0
17	Venkatesh et al.	2020	Blockchain; Social Sustainability; Multitier Supply Chain; Supply Chain Sustainability; Traceability	Robotics and Computer Integrated Manufacturing	19
18	Tan et al.	2020	Blockchain; Green Logistics; IoT; Supply Chains	Sustainability	2
19	Bai and Sarkis	2020	Blockchain Technology; Transparency; Sustainability; Hesitant Fuzzy Set; Regret Theory	International Journal of Production Research	17
20	Köhler and Pizzol	2020	No Keywords	Journal of Cleaner Production	1
21	Nguyen et al.	2020	Blockchain; Artificial Intelligence; Security; Privacy; Machine learning; Deep learning; Coronavirus (COVID-19); SARS-CoV-2; Epidemic	TechRxiv	6
22	Jović et al.	2020	Improving Maritime Transport Sustainability Using Blockchain-Based Information Exchange	Sustainability	0
23	Kouhizadeh et al.	2021	Supply Chain Management; Sustainability; Blockchain; Barrier Analysis; DEMATEL; Technology-Organization-Environment; Framework	International Journal of Production Economics	0

It suggests that sustainability is a topical issue in the application of blockchain technology in supply chain management. Considering that the sustainability effectiveness through blockchain technology in supply chains is clearly increasing (see Figure 1) through the 23 collected references in this study, we expect that this research domain will expand as many companies start adopting blockchain technology in their supply chains [41]. Although the literature on the blockchain with sustainability exists, the potential sustainability indicators have yet to be examined efficiently. This study aims to figure out how to quantify sustainable indicators within the blockchain-based supply chain framework through extensive literature reviews and case studies.

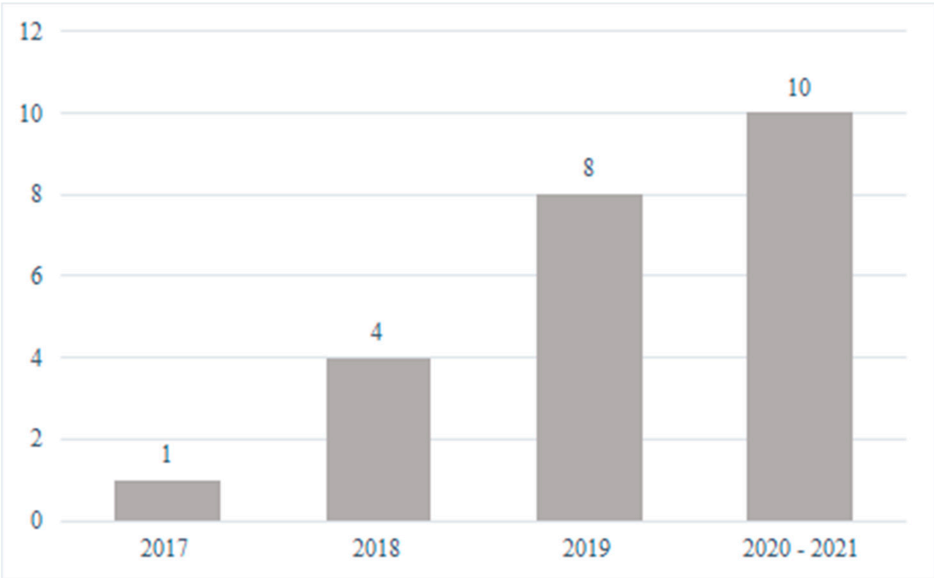


Figure 1. Distribution of published research during the years 2017–2021 based on 23 literature review collections.

4. Blockchain-Based Supply Chain and Its Three Pillars of Sustainability

4.1. Sustainability

The concept of sustainability was first addressed by the World Commission on Environment and Development in 1987 [42]; since then, it has evolved to around 300 definitions for several decades [43]. From the economic point of view, sustainability means that we leave for the future generation "the capacity to be as well off as we are today", quoted from Robert Solow, the 1987 Nobel laureate in economics [44]. Consistent with this line of thought, the most universal and widely adopted definition was provided by the United Nations (UN) in 2005, which stylized the concept of sustainability into three core domains: environmental, social, and economic sustainability, known as the three pillars of sustainability.

The challenges of sustainable development require collective efforts not only from the public sector but also the private sector (people and firms) of society. It becomes critical for firms to ensure the alignment of their business practices with the UN Sustainable Development Goals (SDGs). Specifically, the three pillars of sustainability are reflected by firms' Environmental, Social, and Governance (ESG) engagement and performance. Environmental engagement primarily indicates the external impacts that a company may have on the environment as a side effect of their business. The main criteria of environmental sustainability include the utilization of resources, energy efficiency, the amount of waste, and level of emissions from business activities [2,45]. Social equity is mainly concerned with several issues, such as workplace health and safety, diversity and equal opportunity, gender or racial gaps in wages, and child labor, all of which are part of human rights [38]. The governance performance is related to the company's long-term success and profit. It also covers the company's internal affairs, such as communication among stakeholders, according to the 2019 ESG rating methodology report provided by Morgan Stanley Capital International (MSCI ESG Research, 2019) (https://www.msci.com/documents/1296102/14524248/MSCI+ESG+Ratings+Methodology+-+Exec+Summary+2019.pdf/2dfcaeee-2c70-d10b-69c8-3058b14109e3?t=1571404887226 (accessed on 23 December 2020)). This ESG assessment framework has been broadly discussed and adopted by firms to indicate their sustainable engagement and performance [46,47].

Considering the three pillars of sustainability and the ESG framework, this paper is particularly concerned with the supply chains that incorporate blockchain technology and how this novel technology may contribute to ESG performance. As summarized in Saberi et al. [2], there is increasing popularity in applying blockchain technology to supply chains. In the rest of this section, we conceptualize each indicator in the context of supply chain management and discuss how the blockchain technology's unique characteristics could improve its ESG performance through supply chains.

4.2. Blockchain-Based Supply Chain and Environmental Sustainability

Environmental sustainability is concerned with inter-generational equity of receiving benefits from natural resources and environmental amenities. This issue has drawn significant attention and discussion from academia, industry, and government entities [2,48]. In the context of supply chains, environmental sustainability issues arise from both the early phase where raw material resources flow from the natural environment into the process of production and consumption (e.g., nature–economy interaction), and the later phase, where pollution generated from economic activities flows to the natural environment (e.g., economy–nature interaction). In the early nature–economy interaction, economic activities could lead to natural resources diminishing and deteriorating, thus jeopardizing future generations. In the later phase, the economy–nature interaction is often related to environmental degradation, such as water scarcity, air pollution, and soil erosion, affecting humans' well-being for generations. According to the United States Environmental Protection Agency (EPA), supply chains significantly contribute to a company's environmental footprint, responsible for approximately 40–60% of a manufacturing company's and 80% of a non-manufacturing company's carbon footprint (https://www.epa.gov/sites/production/files/2016-09/documents/improving_sustainability_in_supply_chains_091516.pdf (accessed on 23 December 2020)).

Environmental sustainability within supply chains requires adopting optimal management practices of natural resources and environmental protection policies [49]. Sarkis [45] proposes a strategic decision framework for green supply chain management, highlighting the dynamic nature of businesses and their relationship with the natural environment. Such a dynamic nature requires a real-time monitoring system to update information for all the participants in the supply chains synchronously. The nature of blockchain technology—traceability, reliability, synchronized transaction process, as well as cost efficiency—makes a better supply chain an appropriate alternative to traditional corporate policies and practices to promote environmental sustainability [2]. In particular, blockchain technology can enhance the following two general indicators: (i) Environmental emission abatement: the blockchain technology allows participants in the supply chain to track the location and amount of emissions, especially carbon emissions, wastewater, or toxic pollutants from each step and, therefore, take action to comply with environmental policies. In addition, each participant can make sure their upstream partners do not violate any environmental policy or law. Under this pressure, the supply chain as a whole will intentionally reduce its environmental emissions. (ii) Resource management: blockchain technology enables us to monitor the origins of raw materials, avoiding excessive extraction and utilization of natural resources, and thus helping to prevent issues such as salinization or deforestation. Yet, we do not observe any empirical study showing whether and to what extent blockchain technology could maintain a sustainable resource-use rate. (iii) Waste management: blockchain technology allows businesses to track their waste [27], making it possible to recycle, reuse, or properly take care of those wastes. For example, the IBM Food Trust allows the food supply chain to track the amount of the food waste [26], which can not only minimize costs to blockchain adopters but also protect the environment. It is worth noting that energy efficiency is another area that can benefit from blockchain technology, but that area is typically beyond supply chain management, so we leave it for future study.

4.3. Blockchain-Based Supply Chain and Social Sustainability

Social sustainability is concerned with business impacts on employees, workers, customers, and even local communities in order to support a healthy society [50,51]. Despite the increased attention to social sustainability, this pillar is rarely studied in supply chain management [38,48]. Social sustainability within the supply chains examines social–economic conditions regarding involved employees (e.g., manufacturers and suppliers) in the supply chain, such as safety and human rights (e.g., workplace protection) [52,53]. One of the critical social sustainability issues in the supply chain is how to be socially responsible when buying resources [53]. For instance, Helo and Hao [36] suggest an example of a socially sustainable supply chain based on "blood diamond", which indicates the exploitation of child labor and unethical process of the diamond supply chain [54].

The blockchain-based supply chain has an impact on social sustainability [2]. Specifically, blockchain enables supply chains to maintain secure information, and the "immutable" feature protects all involved parties in the supply chains from corruption—individuals, governments, or organizations. This is because only authorized actors can change the information in the blockchain-based supply chain. Moreover, supply chains procure goods based on reliable suppliers. Blockchain keeps a transparent record of transactions for the whole process, promoting assurance from ethical suppliers. In the blockchain-based supply chain context, Cartier et al. [33] discuss the social issues in the Gem industry. This industry supply chain is growing, especially in the sourcing aspect. The unethical sourcing processes that potentially abuse human rights in the diamond industry are widely discussed. They also point out that the blockchain-based supply chain allows building a transparent procedure by verifying the supplier's operations and preventing any potential unethical sourcing issues (e.g., child labor and human trafficking).

Moreover, unethical sourcing in the fashion industry is discussed from a social point of view [34]. There are many multitier suppliers in this industry, and some suppliers do not have incentives to pursue social sustainability. As a result, unethical issues arising from the suppliers would lead to damage to the reputations, sales, and stakeholder wealth of all relevant supply chain participants [55]. Hence, the blockchain-based supply chain enables us to increase visibility to prevent such unethical sourcing by having greater transparency. Hastig and Sodhi [35] suggest that child labor, rural poverty trap, and standard of living index can be used to evaluate the blockchain-based supply chain's social sustainability. For example, Helo and Hao [36] introduce the Walmart blockchain with the IBM food trust system to explain one of the social sustainability indicators, safety. All players in the supply chains gain data including farm origin, factory and processing data, expiration dates, and delivery details recorded in the blockchain system. Li et al. [37] suggest evaluation criteria from a social perspective based on the literature review by suggesting working efficiency, work safety, and labor health.

In summary, blockchain secures stable and immutable information in supply chains, and these features help to enhance social sustainability and other social dimensions. A transparent information system prevents the corruption of all involved participants in the supply chain (e.g., forgery and nefarious participants). Moreover, traceability supports ethical sourcing by having clear information on product history. Thus, blockchain technology protects human rights and safe and healthy business environments in supply chains [2,23].

4.4. Blockchain-Based Supply Chain and Economic (Governance) Sustainability

Economic sustainability refers to a status where an economy can achieve steady growth without sacrificing social and environmental sustainability. In the context of corporate and supply chain management, the economic sustainability pillar is often referred to as governance. It requires the company to develop a robust management structure that ensures overall transparency, traceability, and accountability, and ultimately can strengthen relations with external stakeholders and attract potential investors [40,48]. Successful sustainable governance offers long term successes to the supply chains, because it can strengthen firms' competitiveness, realize healthy and transparent corporate management, increase profit [28], and help the development of the other two pillars [48]. However, it faces a range of challenges in practice. First, information asymmetry among partners along the supply chains could temper with the transparency management structure. This is particularly true for global supply chains, partly due to increased outsourcing [39]. Second, the lack of reliability is another significant concern for the supply chain governance performance, which can lead to error or corruption issues due to the centralized transaction system [38]. Lastly, it is often the case that traditional supply chain management hardly achieves traceability and reliability at the least possible cost, because it requires a substantial investment and management effort to monitor and trace the whole supply chain. Although most supply chains voluntarily self-regulate, such as the global management system (ISO 14000), it is not a panacea for these challenges.

The factors that drive sustainable governance typically cover two themes: corporate governance and corporate behavior. According to MSCI ESG Research (2019), the former theme can be indicated by board activities, ownership, and accountability (https://www.msci.com/documents/1296102/14524248/MSCI+ESG+Ratings+Methodology+-+Exec+Summary+2019.pdf/2dfcaeee-2c70-d10b-69c8-3058b14109e3?t=1571404887226 (accessed on 23 December 2020)). The latter can be indicated by leadership ethics, corruption and instability, anti-competitive practices, financial system instability, and tax transparency. These indicators are consistent with Hastig and Sodhi [35], who emphasize that capabilities, collaborations, technological readiness, supply chain practices, leadership, and governance of traceability effort could bring supply chain management success. Based on these factors, we believe that blockchain technology could improve supply chain governance performance. We illustrate this from three aspects. First, it allows supply chain participants to instantly access accurate and reliable information, making the whole transaction process transparent and fast. Second, it provides a powerful solution to the asymmetry information issue using the smart contract, by which a transaction is made only when every participant agrees to it, bringing symmetry information among upstream and downstream partners and, therefore, avoiding possible corruption or errors [38]. Last, the historical performance of a supply chain participant, such as on-time deliveries or payments, can be stored on blockchain, which can be further used to establish trust and collaboration among stakeholders [28].

4.5. ESG Ratings

Beyond the conceptual assessment of the three pillars of sustainability, ESG ratings are a widely used tool to show sustainability performance to business leadership, investors, and stakeholders [46,56]. Hence, ESG ratings are indicated in sustainability reports, such as carbon emissions and percentage of the international market. There have been a number of ESG rating agencies providing ESG ratings and scores. Each company has its own criterion and methodology to evaluate its sustainable engagement and performance. This methodology often involves comprehensive data collection and assessment models. The most historical ESG ratings are provided by MSCI, which reports the MSCI ESG ratings of approximately 8500 companies worldwide by assessing 37 ESG key issues within the three pillars. Another popular ESG rating is provided by Sustainalytics. This assesses the extent to which a company's enterprise business value is at risk due to environmental, social, and governance concerns. The rating considers an assessment of a company's exposure to industry-specific material ESG issues in addition to an assessment of how well the company is managing those risks. Yet, these ESG performance criteria are often complicated and vary according to industries and social norms. Hence, those criteria are unlikely to fully represent the company's sustainability assessment process [57]. A more detailed explanation of several other ESG ratings is discussed by Huber et al. [58].

5. Case Study

Below, using two case studies, we evaluate whether the three sustainability indicators can be improved indirectly along supply chains based on blockchain technology. Our evaluation is based on the characteristics of blockchain technology and their relationships to the three pillars of sustainability, as summarized in Sections 4.2–4.4

5.1. Wal-Mart and IBM Food Trust

5.1.1. Background

Motivation of Wal-Mart Blockchain-Based Supply Chain

Traditional supply chains rely on manual processes, requiring a long time to discover the sources and routes of food with safety issues. Many diseases (e.g., *Escherichia coli*) have appeared due to hazardous food for many years. Wal-Mart had massive food scandals related to milk and infant formula across China. Over 300,000 people were negatively affected [59]. Supply chains need to be verified by tracking the source (e.g., origin) to examine food contamination. In this process, it should be quick and accurate to identify food sources. However, companies involve many suppliers and customers, which leads to overloading information regarding products, prices, workforces, documentation, etc. Wal-Mart found that it takes several days to find the origin of products, and this situation shows that their supply chains require improving traceability. In October 2016, Wal-Mart announced a project to track the food distribution process using blockchain technology in partnership with the IBM Food Trust program to resolve the traditional burden of processes.

Pilot Project in Wal-Mart Food Supply Chain

Specifically, Wal-Mart launched two pilot projects aiming to improve food safety in the supply chains of pork products and mangoes. They use blockchain technology to track pork products in China from origins (e.g., farms) to destinations (e.g., Wal-Mart in China) and increase food safety. Moreover, they started monitoring mangoes from Latin America to the United States, which is indicated in the 2017 Wal-Mart Global Responsibility Report [24]. At each step in delivering food from a supplier to a consumer, relevant information, such as the origin information of the food, batch number, factory, processing data, and transportation details, is recorded on the blockchain in real-time. As a result, Wal-Mart achieved a significant improvement through a blockchain-based supply chain system related to a package of sliced mangoes. They reduced the tracking time to obtain origin records in Mexico in 2.2 s. In the past, it took six days based on a paper record-keeping system [24].

Impacts of Blockchain-Based Supply Chains

After a successful pilot for two products (e.g., pork, mangoes) on food safety through blockchain-based supply chains, Wal-Mart requested all their suppliers of fresh leafy greens to use the blockchain system. Moreover, Wal-Mart expanded the blockchain technology to trace the origin of foods such as strawberries, chicken, yogurt, and baby foods. with Hyperledger Fabric in 2018 [60]. This result illustrates that the blockchain-based supply chain system helps to track products, which can improve trust among involved stakeholders (e.g., suppliers and customers) by obtaining accurate and transparent information about their origins and processes. This technology allows supply chains to collaborate more efficiently than before for information sharing. Suppliers need to upload data through the blockchain system [61]. Ultimately, enhanced traceability contributes to the impact on the environmental, social, and governance pillars in their supply chains.

5.1.2. The Effects on Food Trust on Wal-Mart Food Supply Chain Sustainability

Following the above discussion, our primary goal is to evaluate whether and to what extent the IBM Food Trust program, based on blockchain technology, contributes to sustainability within Wal-Mart's food supply chain. To this end, we concentrate on the three most important performance indicators: food waste management, food safety, and product health and nutrition. These three indicators are recognized as the most critical concerns of any food supply chain, as they are highly associated with environmental sustainability through managing waste, social sustainability through protecting consumer welfare, and governance sustainability through minimizing cost.

Food Waste Management by Blockchain

Wal-Mart set a waste reduction goal named Zero Waste in 2005, aiming to reduce 25% of store waste by 2008, including all types of waste, such as cardboard, plastics, metals, food waste, glass, wood, tenant waste, and residual waste (according to the Wal-Mart Sustainability Report, achieving the 5% goal would be the equivalent of taking 213,000 trucks off the road per year, and saving 323,800 tons of coal and 66.7 million gallons of diesel fuel from being burned). Wal-Mart has made progress in reducing waste over time, according to its annual sustainability report. However, this achievement has mainly been attributed to reducing cardboard, not other types of waste, especially food waste. In 2014, Wal-Mart launched a campaign focusing on reducing food waste, but the target was not met in 2015. This was mainly because the food waste management tracking system was insufficient to measure and manage accurately.

In response to this challenge, Wal-Mart moved to another target in 2016, Zero Waste Future, considering the whole food supply chain from farming to manufacturing to consumers. At the same time, this food waste tracking system has been improved by introducing the IBM Food Trust to its food supply chain. The IBM Food Trust creates an intelligent system to trace waste from each stage within the food chain, allowing Wal-Mart to accurately judge the remaining shelf life and make appropriate plans to ensure the freshness of products. It enhances the efficiency and effectiveness of managing waste generated along the food chain. It also reinforces environmental sustainability by tracking and recycling the food packages, which are a major source of waste [27]. As of the end of 2016, Wal-Mart successfully reduced food waste by 15.3% (Wal-Mart Global Responsibility Report, 2016) (Wal-Mart measures reductions in food waste by the following: measurement metric = total weight of non-diverted food in pounds/total weight of all food sold in pounds). Since then, Wal-Mart diverted more than 1.6 billion dollars in 2018 (more than 1.4 billion in 2019) of food waste from landfill globally, receiving the highest score among supermarkets assessed nationwide by the Center for Biological Diversity's food waste study according to the 2019 and 2020 Wal-Mart Global Responsibility Report. In addition, all waste was reduced significantly after 2016. For example, according to Wal-Mart's Global Sustainability Report in 2016, Wal-Mart in the US achieved 82% diversion of materials from landfills and diverted an average of 71% in international markets.

Food Safety, Health, and Nutrition by Blockchain

The IBM Food Trust helps to secure food safety using blockchain technology. Supply chain partners and consumers can access reliable and transparent information on where the ingredients grew, and trace origins and spread if there were any cross-contamination and foodborne illness on the food chains [26]. The availability of this information improves consumer welfare and prevents additional costs for supply chain participants and society. In practice, Wal-Mart attempts to collaborate with upstream partners to ensure accountability, which relies on efficient communication among supply chain partners. In 2017, Wal-Mart collaborated with IBM and Tsinghua University to promote food safety by a blockchain-powered traceability system in China, following a similar application of blockchain technology to the leafy product Wal-Mart US in 2018. Based on the Wal-Mart Global Sustainability Report, food safety issues improved significantly after these two initiatives.

Blockchain technology also brings transparency and visibility to food supply chains, making life-cycle information of a product from farm to table transparent. Consumers can learn any information about the ingredients and origins of any product in seconds, providing a great opportunity for consumers to acquire health and nutrition knowledge.

The Effects on Wal-Mart Overall Sustainability

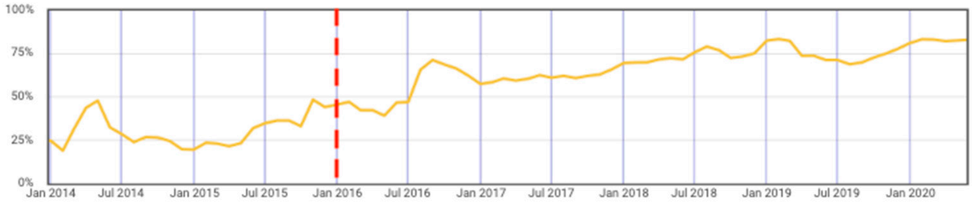
We further investigate whether the IBM Food Trust program promotes Wal-Mart's overall sustainable performance. Wal-Mart has reported its approaches and assessments on environmental, social, and governance performance since 2005. The report covers a series of topics, including its ESG goals, commitments, initiatives, approaches, and progresses. Overall, the ESG performance has improved over time, especially after 2016, when the IBM Food Trust program was first introduced to its food supply chain. To eliminate any biases, we also collected the ESG scores between 2014 and 2020 from the CSRHub Ratings (www.csrhub.com (accessed on 4 February 2021)). CSRHub collects data from ESG analysis firms, NGOs, government databases, publications, and research reports, which are further transformed into a 1 to 100 scale, with 100 as the best rating. The time trend of four indicators for Wal-Mart Stores, Inc. is shown in Figure 2a–e. In general, it is consistent with Wal-Mart's self-evaluations reported in the annual responsibility report. The overall ESG ratings jumped after the second quarter of 2016, and then gradually increased until 2019 when there was another slight increase.

As a piece of additional evidence for Wal-Mart's environmental performance specifically, we applied the product impact measurement framework of the Impact-Weighted Accounts Initiative (IWAI) provided by Harvard Business school [62]. As shown in Figure 3, we plotted Wal-Mart's monetary environmental intensity from 2010 to 2018 using two measurements: "Total Environmental Intensity (Revenue)", which represents the company's environmental damage of water and air emission per unit of sales; "Total Environmental Intensity (Operating Income)", which represents the company's environmental damage to water and air emissions per unit of operating income. This allows us to observe the time trends in their monetary valuation of environmental impacts, including before and after they adopted the IBM Food Trust program in 2016. As shown in Figure 3, the environmental damage per unit of sales gradually decreased over time, especially after 2016, while the environmental damage per operating income increased immediately after 2016 but then gradually declined after 2017. This suggests that the environmental intensity in terms of operating income had a lag to show the effects. Still, in general, the environmental performance showed a significant improvement after 2016, which is consistent with what we found using the ESG score and Wal-Mart Sustainable report, as discussed above.

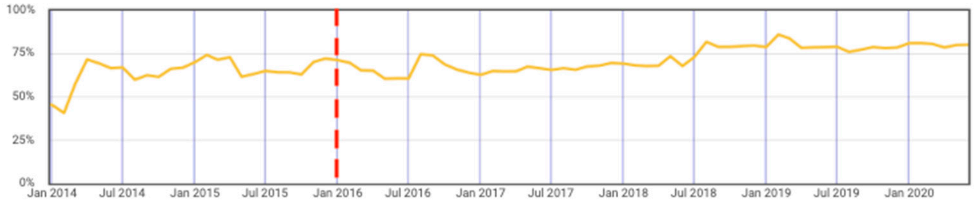
5.2. Maersk with IBM (TradeLens)

5.2.1. TradeLens: Blockchain-Based Supply Chain of Maersk with IBM

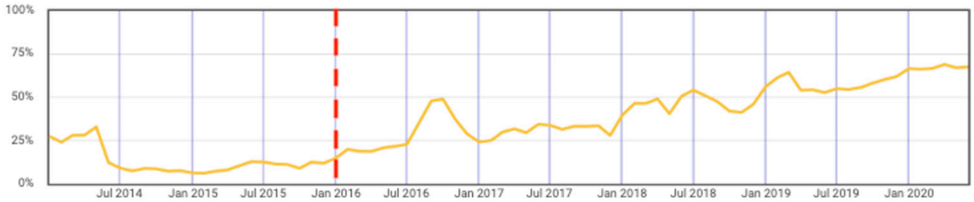
Maersk, an integrated shipping company, launched pilot blockchain technology to enhance global supply chain flow transparency. Partnered with IBM, they established a blockchain-based platform called "TradeLens" in logistics in December 2018. The shipping industry is composed of multiple brokers that cause a long value chain through manual processes in their supply chains [63]. Maersk expected to enhance the transparency of its global supply chain by facilitating global trade using the "TradeLens" platform, which uses blockchain technology to enable users trading in a "simple, secure and real-time environment" [64]. After 2019, this platform solution was used by more than 60 in-network members, including ocean carriers and inland carriers, worldwide ports, and terminals and custom authorities. According to the 2019 Maersk sustainability report (https://www.maersk.com/about/sustainability/our-sustainability-strategy (accessed on 4 February 2021)), they analyzed the trade trends of their terminal in India, and this showed that the simplified transaction processes by the blockchain-based system reduced their total operating costs. In particular, exporters and importers in Mumbai reduced their costs by approximately 15% of total costs than before adopting blockchain technology. Westergaard-Kabelmann (2019) points out that documentation's related average time was significantly reduced thanks to the simplified exchange system with "secure, immutable digital workflow" among all partners via the blockchain-based supply chain system (Mumbai transport study highlights TradeLens value).



(**a**)

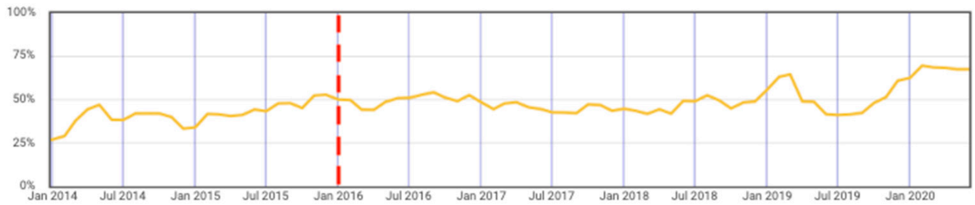


(**b**)



(**c**)

(**d**)



(**e**)

Figure 2. (**a**) Wal-Mart overall ESG rating between 2014 and 2020. (**b**) Wal-Mart environmental sustainability rating between 2014 and 2020. (**c**) Wal-Mart social sustainability rating (employee) between 2014 and 2020. (**d**) Wal-Mart social sustainability rating (community) between 2014 and 2020. (**e**) Wal-Mart governance sustainability rating between 2014 and 2020. Data source for (**a**–**e**): CSRHub Ratings (www.csrhub.com (accessed on 4 February 2021)).

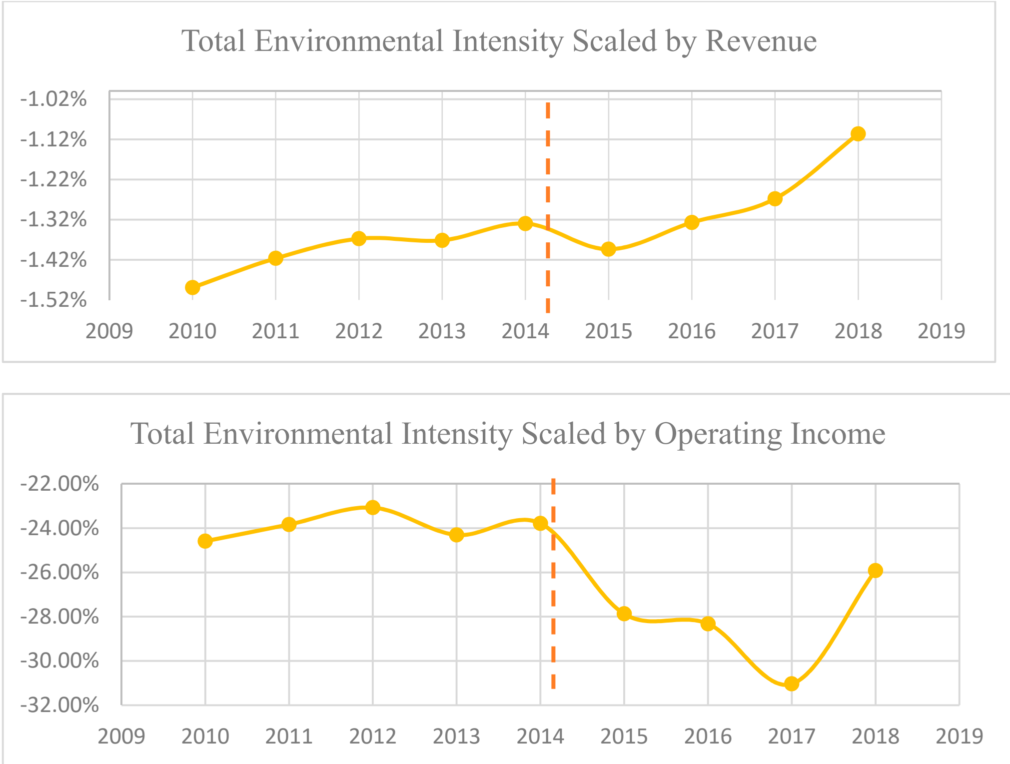


Figure 3. Wal-Mart monetized environmental intensity (data source: IWAI).

As documented in the literature, blockchain technology can contribute to the sustainability performance of the shipping industry. For instance, Jović et al. [32] perform an extensive review of how blockchain-based systems improve maritime transportation sustainability. The blockchain-based system adopts electronic paperwork, which significantly contributes to environmental protection by reducing carbon emissions. Furthermore, a sustainable supply chain contributes to supply chain performances in the logistics domain, ultimately reducing emissions and bringing benefits to public health and the country's reputation [65]. Another potential sustainability benefit is to promote economic growth by reducing shipping costs with high visibility [66,67]. They performed manual processes with multiple brokers in the shipping industry [63]; however, a blockchain-based system will remove those brokers. This direct transaction improves cost-effectiveness (e.g., commission). In terms of social sustainability performance, the blockchain-based system can achieve a better social aspect, enhancing human rights and fair working environments. The blockchain system can monitor the system based on an immutable record system [2,32]. To our acknowledge, there are many potential positive sustainability enhancements by the blockchain-based system in the logistics domain. Below, we discuss how sustainable performance could be improved in Maersk after they adopt TradeLens.

5.2.2. The Effects of TradeLens on Maersk Supply Chain Sustainability

Maersk initiated a pilot program using TradeLens in 2018, so there is no direct evidence for improvement of sustainability performance in their annual reports. Unfortunately, we do not have access to either CSRHub or IWAI to perform a third-party evaluation of Maersk's sustainable performance as we did for Wal-Mart. However, Maersk's annual report showed indirect evidence that the blockchain-based system influenced their overall sustainable performance. In the 2018 Sustainability Report, Ms. Skou, the CEO of Maersk, mentioned: "We continue to develop our blockchain documentation solution, TradeLens, to improve our customer experience and create access to trade, as digitising information can drive down the cost of trade, reduce the occurrence of corruption and support job creation.". In this message, Maersk expected to improve its economic aspect (e.g., cost of trade) and social sustainability (e.g., reducing corruption and supporting job creation) by adopting TradeLens. According to the 2019 Sustainability Report, Maersk introduced its blockchain-based system TradeLens and discussed how the simplified transactions by TradeLens could help to reduce costs. The report covers ESG issues, objectives, and sustainability performance. Despite the fact that they do not show the direct impact of blockchain technology on sustainability, it is evident that there are potential improvements in the future.

6. Conclusions and Future Directions

Improving supply chain sustainability is an essential part of achieving the UN's sustainable goals. The blockchain-based supply chain is gradually growing. Using distributed ledger technology, the blockchain platform provides a digital system and database to record the transactions along the supply chain. All the information is agreed upon and then shared among supply chain actors. This decentralized database of transactions brings transparency, reliability, traceability, and efficiency to supply chain management.

This paper focuses on supply chain management and its sustainability performance in the areas of environmental protection, social equity, and governance efficiency. We assessed the extent to which the three sustainability indicators can be improved along supply chains based on blockchain technology. In light of three bodies of literature, i.e., sustainability, supply chain management, and blockchain-based supply chain, we assembled the studies using systematic literature analysis. We found that studies focusing on the impact of blockchain technology on sustainability are continuously increasing in recent years, claiming the positive effect of blockchain platforms on sustainability.

In addition, we provided a case study on how supply chains can take advantage of blockchain technology by focusing on the collaboration between the Wal-Mart food supply chain and IBM Food Trust. We investigated Wal-Mart's annual sustainable performance report and external ESG ratings before and after adopting the IBM Food Trust. We showed that blockchain technology improves waste management and provides food safety, health, and nutrition along the Wal-Mart food supply chain. This evidence suggests that we could use the potential quantifiable sustainability indicators (ESG ratings) for future study. Additionally, we added another case study related to Maersk in the logistics area. Even though there is no direct evidence suggesting that TradeLens, a blockchain-based system, improved Maersk's sustainability performance, the literature and Maersk's Sustainability Report imply that TradeLens is associated with possible positive performances.

Recently, many companies have been adopting blockchain technology in their supply chains (e.g., Ford, Unilever) not only in the food and logistic industry but also in many other industries, such as healthcare (e.g., Pfizer and Change Healthcare) [41], energy (e.g., Shell and Siemens), bank and finance (e.g., Visa and HSBC), travel (e.g., Delta airline and British airways), insurance (e.g., MetLife and Prudential), and even government (e.g., Seoul Metropolitan Government and Monetary Authority of Singapore). This growing popularity of blockchain technology provides us with opportunities to extend the literature on the effects of blockchain technology on corporate management that are beyond our study. One direction for future investigation could be through the lens of stakeholders (e.g., suppliers, distributors, and end-customers), with implications that could improve the design of blockchain-based sustainable supply chains more efficiently by taking other stakeholders' effectiveness into consideration [25]. In addition, within the scope of sustainability, though this study and the majority of the literature focus on the three pillars of sustainability separately, the three pillars are very likely to reinforce each other. Future work might consider the interacting effects of the three pillars of performance.

Finally, although the literature and the two case studies suggested that supply chain sustainability performances can benefit from blockchain technology, it is worth noting that this article neither estimates correlation nor identifies causal inference between adopting a blockchain-based supply chain and sustainability performance. Even a previous study examined the relationship between the blockchain-based supply chains and sustainability based on the literature [2]. However, given that a growing number of companies have been adopting blockchain technology, an empirical analysis estimating the effects of blockchain technology on sustainability performance could be a promising research question for future investigation with theory development.

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