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Citation:

KHAN, Sharfuddin Ahmed, MUBARIK, Muhammad Shujaat, KUSI-SARPONG, Simonov, GUPTA, Himanshu, ZAMAN, Syed Imran and MUBARIK, Mobashar (2022). Blockchain technologies as enablers of supply chain mapping for sustainable supply chains. *Business Strategy and the Environment*, 31 (8), 3742-3756. [Article]

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Blockchain technologies as enablers of supply chain mapping for sustainable supply chains

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Abstract

The advent of blockchain technologies is transmuting the way conventional supply chains are being managed. Due to the complexity of dealing with many actors involved in the supply chain networks, contemporary supply chains have limited visibility, transparency, and accountability. Likewise, supply chains are increasingly facing the challenge of integration and sustainability. In this vein, blockchain technologies can play a groundbreaking role in improving the traceability, accountability, and sustainability of complex supply chain networks. The present study examines the instrumentality of blockchain technologies in enabling supply chain mapping and supply chain integration. The study also tests the direct impact of blockchain technologies on supply chain sustainability. Data are collected from 132 Malaysian Electrical and Electronics firms using a close-ended questionnaire. The study employs Partial Least Squares-Structural Equation Modelling (PLS-SEM) and Partial Least Squares-Multi Group Analysis (PLS-MGA) for analyzing the hypothesized relationships. The results show that blockchain technologies do not have a direct impact on supply chain sustainability. Nevertheless, this finding reveals a robust indirect effect of BT, through SC integration and SC mapping, on the SC sustainability. The study's findings imply that the notion of the sustainable supply chain can be significantly attained by mapping upstream, midstream, and downstream supply chains. The well-mapped supply chain can further improve supply chain sustainability. The findings of the study also suggest the adoption of blockchain technologies as a broad-based strategy to attain multi-tier goals, for example, supply chain mapping, sustainability, and integration.

KEYWORDS

blockchain technologies, mapping, PLS-MGA, PLS-SEM, supply chain integration, supply chain sustainability

Abbreviations: BT, blockchain technology; FMM, The Federation of Malaysian Manufacturers; GSLT, general living system theory; PLS-MGA, Partial Least Squares-Multi Group Analysis; PLS-SEM, Partial Least Squares-Structural Equation Modelling; SC, supply chain; SCI, supply chain integration; SCS, supply chain sustainability; TEEAM, The Electrical and Electronics Association of Malaysia.

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1 | INTRODUCTION

Blockchain technology (BT) is considered one of the leading disruptive technologies that radically transform businesses and supply chains (Saber et al., 2019). BT can improve supply chain visibility, integration, and sustainability (Korpela et al., 2017). It can play an instrumental role in creating an integration among supply chain (SC) partners, making supply chains more visible and traceable (Casado-Vara et al., 2018; Saber et al., 2018). One of the critical challenges faced by supply chains is visibility. Generally, supply chains are complex, geographically spread, and multi-tiered networks (Ali et al., 2021; Ivanov & Dolgui, 2020; Mubarik et al., 2019; Mubarik, Rasi, et al., 2021). Due to this innate complexity and vast length and breadth of SC network, companies start to lose visibility over the topology of their supply network. The seriousness of this challenge was highlighted by the study of Achilles (2013), which mentions, “40% of companies who sourced only in the UK, and almost 20% who sourced globally, had no supply chain information beyond their direct suppliers.”

This invisibility of supply networks severely hampers an organization's capacity to respond to any supply chain disruption. This is why firms' supply chains are struggling hard to cope with COVID-19 effects and putting their best to secure the supplies of components and raw materials to keep their supply chains afloat (Choi et al., 2020; Mubarik, Naghavi, et al., 2021). However, the lack of supply chain mapping and weak SC integration, resulting in unavailability or inaccessibility to critical information, have created a big hurdle to respond to the disruption caused by COVID-19. It has led to a reactive, unorganized, and subtle response to unprecedented disruptions. This demands a well-mapped supply chain, which enables complete SC visibility, traceability, and sustainability (Mubarik, Naghavi, et al., 2021). SC mapping is becoming an increasingly urgent requirement and a fundamental differentiator of a firm. Companies are using it to attain supply chains sustainability, integration, and visibility.

Nonetheless, as to how the supply chain can be mapped is a big challenge for both practitioners and researchers. BT, in this regard, can play a very critical and valuable role by enabling firms to map the supply chain. The state-of-the-art nature of BT allows a firm to real-time visualize and track the upstream, midstream, and downstream supply chains (Mubarik & Zuraidah, 2019; Mubarik, Naghavi, et al., 2021).

The second challenge that an organization's supply chains tend to face is sustainability, closely connected/related to SC visibility. The invisible SC processes lead to compromise sustainability of supply by hiding the SC processes from the firm. Since a company cannot trace or see its supply chain processes, it becomes highly challenging to ensure the sustainability of each process. The lack of sustainability can further lead to strategic and reputational competitive issues. The above two critical challenges have prompted the SC researchers to think of a technologically driven model, which can simultaneously cater to a firm's supply chain mapping, integration, and sustainability. Further, managing supply chains to attain local and global sustainability goals is critical for firms worldwide. BT, in this regard, can offer significant implications. Due to the early stage of BT implementation, its

role in supply chain sustainability and integration is less understood, and the intent to adopt it for supply chain mapping is unknown. This can be realized from the fact that a vast majority of SC professionals have very limited or no information about blockchain technology and its role in the supply chain.

Further, despite BT's massive potential to transform the supply chains, it is new in the market, making it challenging to effectively predict its performance outcomes (Francisco & Swanson, 2018; Tian, 2016). Organizations are highly cautious in implementing BT as they are not convinced as to how BT-driven-SC can influence their crucial supply chains indicators like sustainability, traceability, and integration (Orji et al., 2020). Such companies tend to weigh the benefits of BT against its implementation challenges and other associated costs (Bai & Sarkis, 2017). The reluctant behavior of firms is due to the fact that there is no scholastic or practical work at a large scale to demonstrate how blockchain technologies implementation can affect supply chain sustainability, traceability, and other parameters (Bai & Sarkis, 2020; Mubarik, Naghavi, et al., 2021). Many organizations have expressed their hesitation to the most unfamiliar areas of applying blockchain technology to their supply chain processes, such as mapping, integration, and traceability of information.

Presently, the majority of research work on BT tends to present either a case base application or experts' opinions. However, there is a void of studies that systematically examine the impacts of blockchain technology on supply chain integration, mapping, and sustainability. The ability of BT to map and track upstream, midstream, and downstream supply chains has not been used as a core criterion in any evaluation technique. This gap creates complexities that include inter-organizational consensus (Kamble et al., 2019). Therefore, we study this sphere by focusing on the impact BT on supply chain mapping and supply chain sustainability as well as the impact of BT on supply chain integration and supply chain sustainability with a particular focus on the Malaysian Electrical and Electronic (E&E) sector.

The Malaysian E&E industry was chosen since it is one of the significant contributors to the Malaysian manufacturing sector's GDP and export (MIDA, 2020). Further, the Malaysian E&E industry is also considered the most vibrant industry in the region. Partial Least Squares-Structural Equation Modelling (PLS-SEM) and Partial Least Squares-Multi Group Analysis (PLS-MGA) were employed to analyze the hypothesized relationships. The primary reason for employing the PLS is its ability to handle the non-normal data. According to Black and Babin (2019), “[PLS-SEM is suitable]” when the analysis is concerned with testing a theoretical framework from a prediction perspective. To examine the difference in the results across firm size, we employed PLS-Multi Group Analysis (MGA). It is considered as one of the robust techniques for group comparison (Black & Babin, 2019).

By focusing on the Malaysian Electrical and Electronics sector, this study contributes to BT and Supply chain literature in three ways. First, the study demonstrates, at a larger scale, as to how BT can contribute to the supply chain mapping of a firm and sustainability. Likewise, the study also investigates BT's direct impact on supply chain sustainability through SC mapping and SC integration. Second, the study provides an empirical foundation to theoretically establish the

association between BT and SC mapping, integration, and sustainability. Third and finally, the study offers an implementable framework for organizations to attain BT-led sustainability.

2 | LITERATURE REVIEW

Before discussing BT's theoretical and empirical association with various SC filaments, the following section is dedicated to explaining the definitions and dimensions of BT, SC integration, mapping, and sustainability.

2.1 | Definitions and dimensions

2.1.1 | Blockchain technology (BT)

BT is a database distribution of archives or mutual ledgers, private or public, of all occurrences happening digitally that have been shared and executed among the BT participants (Crosby et al., 2016). BT surfaced in the cryptographic money markets as an innovative technology making disruptions (Nakamoto & Bitcoin, 2008). The BT center is identified with a circulated data set (records) that acts as a synchronized and shared environment (chain), in which data is approved by the clients (Aste et al., 2017; Kano & Nakajima, 2018).

It got mainstream attention through the progression of cryptographic money and bitcoin after the financial emergency of 2008 (Nakamoto, 2019). Although the primary attention had been on financial functions, the remarkable qualities of BT stimulated more extensive utilization of this innovation in various business sectors and multiple marketplaces as well as for non-financial commercial objectives. The energy industry (Mengelkamp et al., 2018), medical care (Mettler, 2016), government (Ølnes et al., 2017), real-estate (Veuger, 2017), and supply chains (Burger et al., 2016) are some of the domains that have applied successful BT applications.

Past studies contemplating the utilization of BT in SCM are developing at a faster pace. The primary utilization of BT in SCM incorporates sharing of data (van Engelenburg et al., 2019), upgrading resilience in SC (Min, 2019), emissions exchanges (Khaqqi et al., 2018), smart contract exchange (Sikorski et al., 2017), SC traceability (Kshetri, 2018), intelligent transport systems (Lei et al., 2017), evading phony or fake items and dishonest conduct (Montecchi et al., 2019), improvement in security (Dorri et al., 2017), interruptions in governance (Shermin, 2017), improving sustainable implementation (Kshetri, 2018), and lowering carbon impressions (Liu et al., 2019).

2.1.2 | Supply chain sustainability (SCS)

SC systems and practices are likewise encountering the rising requirements to confirm and consider SCS. The triple bottom line framework identified in the sustainability concept incorporates a parity of business, social, and ecological measurements while dealing with SC

(Ahmed et al., 2019; Kusi-Sarpong et al., 2021; Seuring et al., 2008). A significant fundamental and crucial challenge for sustainability in SC is the verification and corroboration that activities, goods, and processes inside the SC meet specific sustainable certifications and criteria (Grimm et al., 2016; Khan et al., 2021; Kusi-Sarpong et al., 2019).

The management of SC is vital for overseeing local and global levels of sustainability. Whether the emphasis is on green and natural activities or social obligations, the most significant impacts are SC's activities. Compared to other innovative digital development in technology, BT can have substantial ramifications for sustainable SC, otherwise called technology for distributed ledgers. With developing demand from partners, firms worldwide are zeroing in on their triple-bottom-line monetary, social, and natural performance (Elkington, 1998). Empirical and analytical exploration of sustainable processes has looked at issues, such as inventory management, reverse supply chains, new product design, supply chain design, technology selection, and remanufacturing.

Scholarly studies on sustainable SC management and design have evolved significantly in recent decades (Chan et al., 2017). SCS accomplishments have been substantially centered around decreasing the SC's ecological effects, usually directed toward ozone harming substance discharges and efficient utilization of resources (Yu et al., 2017). Past SC literature highlights lean practices, linkage with productivity, and sustainable practices as the essential component of SCS. For instance, the identification that sustainable SC focuses on decreasing safety inventory and stock points in the SC and exercises of single sourcing with sustainable suppliers (Ahi & Searcy, 2015).

2.1.3 | Supply chain mapping

From the mid-1980s, the studies on the mapping of SC have included pictures, drawings, and diagrams of the organization's chains of supply. A few figures introduced in early studies are usually referred to in past studies, and their impact continues today. They reveal SC's various features. For example, prior research centers around inward processes and gives a linear portrayal of their integration (Stevens, 1989). Another study features the structure of the chains, at first being linear and then being network and the number of tiers. This study also contends for investigations incorporating numerous levels from dyad to chain to a network (Mentzer et al., 2001). A few charts are fixed on a central organization with an upstream SC (suppliers at the start) as well as a downstream SC (till end clients) (Lambert et al., 1998), a portrayal repeated in the broadly utilized reading materials (Slack & Brandon-Jones, 2018). In one model, the investigators recognize participants, streams (product and data), processes in business, and SC mapping elements (Cooper et al., 1997).

It very well might be difficult for an organization to do its SC mapping and to distinguish where is the location of its suppliers (i.e., suppliers of supplier—tier 1), how are they connected, their difficulties in exercising sustainability, and afterward to recognize how to draw in with them to improve their sustainability activities (Kashmanian, 2017). While it might be complex to incorporate

suppliers of tier 1 in this mapping, in an organization's ecological footprint, these tier 1 suppliers may signify more influences and more critical difficulties for the organization to address than any other issues regarding sustainability (Sisco et al., 2011). BSR (2015) indicated, as a primary phase, it is frequently most easy, to begin with, an image of the general SC for the business or item/s that the organization is selling and fill in holes, including the beginning of the raw material input sources.

SC mapping can lead an organization to recognize the prospects and opportunities to decrease the threats to SC by ascertaining when and where to connect successfully with its manufacturers and suppliers to develop their capacity and capability regarding improving toward its and their sustainability objectives (Kashmanian, 2017). For instance, as a major aspect of its SC risk evaluation, Danone worked with The Forest Trust and its providers/suppliers to map its supplier sources to the palm oil plant and afterward started attempting to map from the palm oil factories to the palm oil ranches to enhance its efforts for SC traceability and transparency (Danone, 2015). The organization recognizes three degrees of the need of danger—indirect risks, low priority, and high priority—and the quantity of palm oil plants and mill operators that it believes as an indirect risk or high priority.

2.1.4 | Supply chain integration (SCI)

SCI is the strategic collaboration among the stakeholders of the SC. It is used to develop the firm's inter and intra management practices (Shou et al., 2018). SCI exercises create efficiency and effectiveness through the SC, involving decision-making concerning capital, information, services, resource management, and material flows (Sengupta et al., 2006). These strategic initiatives are mostly led in the SC by important manufacturers emphasizing integrating activities with customers, suppliers, or both sides, relying on the perceptions of the organization about its strategic assets (Wiengarten et al., 2016).

SCI is a multi-feature process that often contains internal and external (i.e., suppliers and customers) integration (Alfalla-Luque et al., 2013). External integration is defined as the collaboration and communication between the producer and its supplier/customer. It also refers to the customer's/supplier's involvement in the organization's internal activities (Wang & Zhang, 2020). Internal integration is considered as the participation of an internal team of SC by performing several tasks while making decisions (Koufteros et al., 2005). The major objectives of SCI are to encourage innovation and creativity while efficiently addressing the dependency related to the processes, goods, and SC design decision-making (Zhang et al., 2018).

SCI exercises are applied to align goals and objectives, simplify the tasks, and prevent conflicts among the external and internal participants of the SC (Flynn et al., 2010). It is beneficial for the firm to involve several stakeholders in operational activities to help identify ideas for the problems and their solutions for the SC design (Petersen et al., 2005). Additionally, the expertise of various departments can be established and enhanced by merging them through the integration process among external entities and producers of the SC to develop innovations and knowledge (Zhang et al., 2018). SCI also allows the

producer to expand the product line by swiftly introducing new products (Tracey, 2004). SCI helps the manufacturer develop new and innovative products and improve its portfolio and performance (Koufteros et al., 2005).

2.2 | Theoretical exposition

General systems theory (GST) provides the foundations for modeling the BT with SC integration, mapping, and sustainability. The GST, as a theoretical foundation, proposes to find out the source of the entire system of collaboration, which results in enhancement and advancement in specialized domains (Rousseau, 2015). It provides a holistic view of new technology adaptation for staying competitive in the market (Fantazy et al., 2016). Zelbst et al. (2010) indicate that the General living system theory (GLST), an expansion of GST, offers firms and their subsystems such as SC by adapting and integrating new resources such as blockchain technologies for improving SC traceability and mapping. These technologies result in helpful information availability by rapidly transferring data to help in effective decision-making for SC mapping processes (Zelbst et al., 2012). Based on GLST, we usually assert that RFID technology serves as a foundation for IoT implementation. All three technologies combine to form a system that improves end-to-end SC traceability and mapping (Elias Mota et al., 2020; Zelbst et al., 2019).

Figure 1 displays the theoretical SC mapping Model. In the model, BT utilization is an antecedent to both SC mapping and integration. BT provides the basis for SC mapping, which in turn affects SC integration. The end goal of all of these technologies is to combine and fuse to impact SC sustainability positively.

2.3 | Hypotheses development

2.3.1 | Impact of Blockchain technologies on SC sustainability

BT can significantly improve SC sustainability. One way to build SC sustainability is to visualize the data and dive deep into it for zooming in the micro-processes to identify the waste. Further, the security of the data also proves essential in this regard. Given that data cannot be altered without being approved by permission from SC participants, BT can avert unethical government, organizations, and associations from holding onto resources of individuals unjustifiably. Additionally, BT can hinder corrupt individuals and consider the dishonest responsible for social and individual wrongdoings (Elias Mota et al., 2020; Mubarik, Naghavi, et al., 2021; Saberi et al., 2019). The traceability practices built within BT helps sustainability through better surety of safe and fair work practices and human rights. For example, transparent entries of the goods history help assure purchasers that supplies being bought are from those sources which are ethical.

H1. Blockchain technologies improve the SC sustainability of a firm

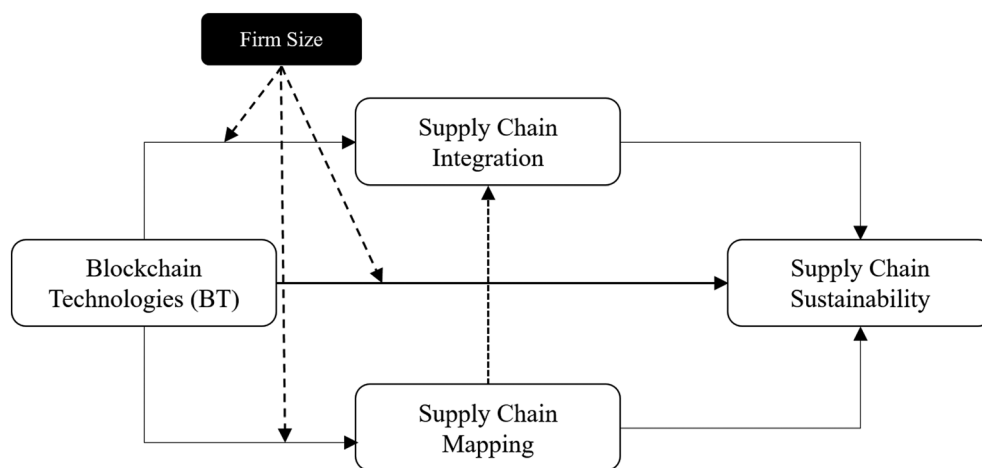


FIGURE 1 Conceptual framework

2.3.2 | Impact of blockchain technologies on SC integration

Past research has acknowledged the SCM–blockchain connection in established SCM domains, for example, anti-counterfeiting practices, intelligent transport approaches, merchandise traceability, and SCM distribution (Queiroz et al., 2019). However, the investigations about SCM integration–blockchain in other conventional SCM themes—are limited, such as quality, procurement, customer relationship management, production/parcel sizing, vehicle routing problems, network modeling, warehouse management, inventory, and so forth. One of the focal functions of the SCM–blockchain linkage is to support knowledge gap planning, principally through adopting novel technological advancements for SCM integration (Ali et al., 2021; Denyer & Tranfield, 2009).

H2. Blockchain technologies positively impacts the SC integration of a firm

2.3.3 | Impact of Blockchain technologies on SC mapping

BT is viewed as delivering security, authorization, verification for authenticity, and accessibility to data for the firm's SC (Cottrill, 2018; Mahmood & Mubarak, 2020). As indicated in past research, BT is a mutual ledger for documenting the historical backdrop of exchanges/transactions (monetary or non-monetary) that are unchangeable once recorded (Zelbst et al., 2019). SC utilizing BT will have a mutual record. Every exchange made by SC partners is placed into a block. The block of exchanges for all SC partners is linked and blocked collectively, and the records are irreversible in the SC. If the data are modified in any capacity, the issue will be apparent that the data is altered to the SC participants, thereby providing a map for every transaction (IBM, 2018; Mubarak, Kusi-Sarpong, et al., 2021; Mubarak, Naghavi, et al., 2021). Similarly, RFID merged into the IoT also gives a mapping process for entering close to real-time data into blocks, while manual

records, for the most part, infers a pause in the entry of information into the blocks. This sort of system provides an opportunity that is vital to improving SC traceability, transparency and advancement in the management of SC (Ali et al., 2021; Srivastava, 2010) as well as brings about a positive effect in digitally mapping the supply chain:

H3. Blockchain technologies positively impacts the SC mapping of a firm

2.3.4 | Impact of SC integration on SC sustainability

SC sustainability practices are enabled by encouraging external and internal factors (Gimenez & Tachizawa, 2012). These enablers are characterized as exercises that help organizations achieve sustainability. SCI is one of the crucial operational exercises inside firms SC (Zhang et al., 2016). In order to sustain quality and strategic partnerships, suppliers have to be integrated into a firm's processes to incorporate the sharing of crucial data, including suppliers in the designing programs as well as the improvement in the process of product development (Li et al., 2005; Mubarak, Naghavi, et al., 2021). With these integrated alliances, organizations form strategic relationships and maintain long-term systematic partnerships with key suppliers by creating a harmonious culture and shared trust (Kang et al., 2018). The expanding significance of the role of suppliers is causing firms to develop strategies by integrating them into their sustainable practices. Such organizations become significant in empowering sustainable management processes through SCI (Paulraj, 2011).

H4. Supply chain integration positively impacts the supply chain sustainability of a firm

2.3.5 | Impact of SC mapping on SC sustainability

Before identifying the SC mapping, it is imperative to comprehend the more general motivation behind SCM. Seemingly, the central idea

behind efficiently managing the SC is integrations within an organization (Ali et al., 2021; Fabbe-Costes et al., 2020; Mubarik, Bontis, et al., 2021). An early explanation of the standards of SC mapping focused on the issues that emerge from the absence of an integrated strategy between the capacities inside a firm (Houlihan, 1983). The answer for these SCM issues is as follows: The whole SC, from materials bought from suppliers to goods distributed to the client, is treated as a unified activity. The method to deal with indirect and direct logistics practices is to horizontally incorporate them on a level plane along with the SC. Earlier studies have contended for integrations inside the firm. However, SC mapping was immediately encompassed to incorporate coordination among firms, and integration in this sense has become a broadly investigated issue (Ali et al., 2021; Frohlich & Westbrook, 2001).

H5. SC mapping positively impact SC sustainability of a firm

3 | METHODOLOGY

3.1 | Population and sampling

The study was conducted in the Electrical and Electronics sector of Malaysia. Malaysian E&E industry is one of the significant contributors to the Malaysian manufacturing sector's GDP and export. According to the MIDA (2020), "The E&E industry in Malaysia can be classified into four sub-sectors, namely, electronic components, consumer electronics, industrial electronics, and electrical products." The list of the registered companies was obtained from The Federation of Malaysian Manufacturers (FMM) and The Electrical and Electronics Association of Malaysia (TEEAM). We approached 280 firms for data collection from January 2020 to April 2020. Due to COVID19 outbreak, the data collection became highly challenging, especially collection through on-site visits. Therefore, the firms were approached electronically using various means. With persistent efforts, we could manage to collect data from 132 firms. Table 1 shows the details of the respondent firms in terms of size, ownership, age, and sub-sector.

To examine any non-response bias, we compared the characteristics of respondents (firm size, age, geographical dispersion, and employees) with those of non-respondents. We could not find any statistically significant difference in the percentage of respondents and non-respondents across various categories. One of the major reasons for the unbiased response rate was survey design, which helped the data collection team to follow up the targeted respondents unequivocally.

3.2 | Data collection instrument

Data were collected through the close-ended questionnaire. The constructs were adapted from the previous sources. The construct of Blockchain Technology (BT), comprising of seven items, has been adopted from Cottrill (2018). Further, the construct of supply chain

TABLE 1 Respondents demography

Sub-sector		
Consumer electronic	73	55%
Industrial electronic	59	45%
Size		
Medium ^a	56	42%
Large ^b	76	58%
Ownership		
Local (Malaysian owned)	65	49%
Joint venture (local and foreign)	51	39%
Foreign owned	16	12%
Firm age (years)		
1 to 9	23	17%
10 to 19	63	48%
≥20	46	35%

^aThe employment size between 75 and 200 (Source: National SME Development Council (NSDC) (2005)).

^bshow the employment size >200 (Source: National SME Development Council (NSDC) (2005)).

mapping (SCmap) was adopted from Mubarik et al. (2020). It is a second-order construct having three major dimensions, namely upstream mapping, downstream mapping, and midstream mapping, with 25 items. The construct of supply chain integration was adopted from multiple studies, notably Cagliano et al. (2006), Flynn et al. (2010), and Frohlich and Westbrook (2001). It is also a second-order construct with three major sub-dimensions, namely internal integration, customers' integration, and suppliers' integration, with a total of 18 items. Finally, the measure of Supply chain sustainability was adopted from the study of (Gouda & Saranga, 2018), having three major dimensions and 09 items. All the items were measured on the Likert scale of 05, where 01 for strongly disagree to 05 for strongly agree. Table 2 exhibits the constructs, their sub-construct, items, and sources. We included firms' size (medium and large) and age as the control variables.

3.3 | Analytical methods

We employed partial least square-based structural equation modeling (PLS-SEM) for analyzing the hypothesized relationships. The use of PLS-SEM was preferred over other techniques due to its robustness (Hair et al., 2016; Mubarik et al., 2016). PLS-SEM, unlike CB-SEM, does not require uni-variate and group normality of the data for the analysis. It is also a preferable approach while testing the application of a developed model (Hair et al., 2016). PLS-SEM is applied in two stages (Dias et al., 2021). At the first stage, the reliability, validity, and fitness of the measurement models are ascertained. At the second stage, path analysis is conducted to test the developed hypotheses. Further, to analyze the stability of results across the firm's size, we employed Multi-group analysis using PLS.

TABLE 2 Constructs

Construct	Sub-construct	Items	Sources
Blockchain technology measurement	—	7	Cottrill (2018)
Supply chain mapping	3	25	Mubarik, Naghavi, et al. (2021)
Supply chain sustainability	3	9	Gouda and Saranga (2018)
Supply chain integration	3	18	Cagliano et al. (2006), Flynn et al. (2010), Frohlich and Westbrook (2001), Vereecke and Muylle (2006), Ellinger (2000), Thomé et al. (2014), Lengnick-Hall et al. (2013), Zhao et al. (2008), Frohlich and Westbrook (2001)

4 | RESULTS

4.1 | Reliability, validity and fitness of constructs

We evaluated the reliability and validity of the measurement models by employing the criteria recommended by Hair et al. (2016). First, we assessed the reliability of the constructs by checking the values of CR and CB alpha. According to Hair et al. (2016), the threshold value of CB alpha and CR for ascertaining the internal reliability of a construct is 0.70. The results in Table 3 show that all of the constructs have these values above 0.70. Further, we also examined the values of factor loading for ensuring reliability. Our results show that all of the items have factor loading of 0.68 or above, depicting robust indicator reliability.

To evaluate the constructs' validity, we employed a twofold approach as recommended by Black and Babin (2019). It examines discriminant validity and convergent validity. For a construct to be convergent valid, the value of its AVE should be greater than 0.50 (Hair et al., 2016). Results of AVE in Table 3 illustrate that all constructs have AVE values higher than 0.50. Thus all constructs have convergent validity. For discriminant validity, we employed the Fornell-Larcker criteria. The results appear in Table 4. The diagonal values in Table 4, which are square rooted values of AVE, are greater than inter-constructs correlation, thus echoing the discriminant validity of all the constructs. Taken together, the results of AVE, CR, loadings, CB alpha, and fitness show the reliability, validity, and fitness of all of the constructs.

It is important “to address potential issues of endogeneity due to potential omitted variables, omitted regressors and simultaneity” (Mora-Monge et al., 2019, p. 530). In order to investigate the presence of endogeneity, we conducted the Hausman test of endogeneity. The insignificant p value (.341) rule out the endogeneity issue.

4.2 | Path analysis

The results of the hypotheses testing are illustrated in Table 5. The results of the first hypothesis ($\beta = .13$, t value 1.182) do not show any significant impact of BT upon SC sustainability of a firm. Further, the results demonstrate a significant direct effect of BT on SC integration ($\beta = .37$, t value 4.111), thus supporting H2a. Likewise, the results

show a significant positive impact of SC integration on SC sustainability ($\beta = .42$, t value 3.818) and support H2b. Taken together, the results of H2a and H2b show a moderate indirect impact of BT, through supply chain integration, on supply chain sustainability. The results also show a substantial effect of BT on SC mapping ($\beta = .53$, t value 3.76) and SC mapping on SC sustainability, confirming H3a and H3b. These results confirm the significant mediating role of SC mapping in the association between BT and SC sustainability. The effect sizes in all supported hypotheses are moderately strong, as reflected by the value of f -square in Table 5.

Further, the value of R -square (0.69) shows a substantial variation in supply chain sustainability, that is, 69% explained by all the independent variables jointly. The value of Q -square (0.415) shows that model has high predictive relevance and results are stable enough to be used for forecasting. In a nutshell, we do not find any evidence regarding the direct impact of BT on sustainability. However, we find BT's highly significant and positive role, through supply chain integration and supply chain mapping, on SC sustainability.

To check the stability of the results across firm size, we divided the data by firm size (medium and large) and employed multi-group analysis (PLS-MGA). The results are exhibited in Table 6. The results show that the impact of BT on SC sustainability (WS p value .481), SC mapping (WS p value .58), and SC integration (WS p value .347) do not significantly differ by firm size. Likewise, the impact of SC integration on SCC sustainability (WS p value .089) is stable across the firm size. Nevertheless, the impact of SC mapping on SC sustainability (WS p value .481) and SC Integration (WS p value .481) differ by firm size. The magnitude of the effect decreases as the firm size does.

We employed Harman's one-factor test (Harman, 1976) for detecting the common method biases. All items were loaded into one common factor. The highest total variance of any single factor was 29%, which rules out the possibility of CMV. Additionally, the values of VIF are less than 3, supporting the findings of the Harman test.

5 | DISCUSSION

Our results echo the findings of the other studies, for example, Wu et al. (2017), Mackey and Nayyar (2017), and Mubarik et al. (2020). According to Queiroz et al. (2019), “blockchain technologies have the capacity and flexibility to be applied to different SCM contexts. For

TABLE 3 Reliability, validity and model fitness

Construct	Sub-dimensions	Loadings	Code	Loadings	AVE	CR	CB alpha					
Blockchain technologies			BCT1	0.71	0.55	0.9	0.77					
			BCT2	0.75								
			BCT3	0.78								
			BCT4	0.73								
			BCT5	0.72								
			BCT6	0.82								
			BCT7	0.69								
Supply chain mapping (AVE 0.54; CR 0.78)	Upstream mapping	0.71	SCM1	0.75	0.62	0.93	0.79					
			SCM2	0.81								
			SCM3	0.71								
			SCM4	0.74								
			SCM5	0.75								
			SCM6	0.78								
			SCM8	0.83								
			SCM9	0.87								
			SCM10	0.81								
			Midstream mapping	0.74				SCM11	0.72	0.56	0.88	0.81
	SCM12	0.74										
	SCM13	0.77										
	SCM14	0.76										
	SCM15	0.73										
	SCM18	0.78										
	Downstream mapping	0.76			SCM19	0.81	0.63	0.91	0.74			
					SCM21	0.89						
			SCM22	0.71								
			SCM23	0.83								
			SCM24	0.77								
			SCM25	0.75								
			Supply chain sustainability (AVE 0.57; CR 0.80)	Environmental sustainability	0.72	SCS1				0.71	0.5	0.75
	SCS2	0.68										
	SCS3	0.73										
	Social sustainability	0.74		SCS4	0.81							
SCS5				0.77								
SCS6				0.73								
Supplier sustainability development	0.81	SCS7		0.75								
		SCS8		0.73								
		SCS9		0.71								
Supply chain integration (AVE 0.60; CR 0.82)	Supplier integration	0.73	SCI1	0.81	0.62	0.89	0.74					
			SCI2	0.77								
			SCI4	0.83								
			SCI5	0.79								
			SCI6	0.72								
			Internal integration	0.79				SCI7	0.76			
	SCI8	0.69										
	SCI9	0.74										
	SCI11	0.68										

(Continues)

TABLE 3 (Continued)

Construct	Sub-dimensions	Loadings	Code	Loadings	AVE	CR	CB alpha
	Customers integration	0.81	SCI12	0.73	0.57	0.89	0.85
			SCI13	0.68			
			SCI14	0.82			
			SCI15	0.77			
			SCI17	0.81			
			SCI18	0.73			

Note: Items SCM7, SCM16, SCM17, SCM20, SCI3, SCI10, and SCI16 have been deleted due to low factor loading.

TABLE 4 Fornell-Larcker criteria

	VIF	BCT	SCM	SCS	SCI
Blockchain technology (BCT)	1.58	0.74			
Supply chain mapping (SCM)	2.91	0.37	0.73		
Supply chain sustainability (SCS)	2.47	0.46	0.57	0.75	
Supply chain integration (SCI)	1.87	0.48	0.38	0.51	0.77

Note: Values in diagonal are square roots of AVE.

TABLE 5 Structural model hypotheses testing

Hypotheses	Relationship(s)	Beta	S.E	t-value	Decision		f^2	q^2
					p value	Accept/reject		
H1	BT → SC sustainability	.13	0.11	1.182	.241	Rejected	0.014	0.001
H2a	BT → SC integration	.37***	0.09	4.111	.000	Accepted	0.175	0.091
H2b	SC integration → SC sustainability	.42***	0.11	3.818	.000	Accepted	0.192	0.081
H3a	BT → SC mapping	.53***	0.14	3.786	.001	Accepted	0.254	0.14
H3b	SC mapping → SC sustainability	.36***	0.08	4.500	.000	Accepted	0.187	0.17
H4	SC mapping → SC integration	.28***	0.05	5.600	.000	Accepted	0.143	0.002

Note: R^2 (Supply Chain Sustainability 0.687). Effect size are according to Cohen (1988), f^2 values 0.35 (large), 0.15 (medium), and 0.02 (small). Q^2 (Supply Chain Sustainability = 0.415); Predictive relevance, q^2 , of predictor exogenous variables as according to Henseler et al. (2009), q^2 values 0.35 (large), 0.15 (medium), and 0.02 (small).

*** $p < .01$. ** $p < .05$.

TABLE 6 Multi-group analysis

Hypotheses		Large	Medium	M-S	(WS) p value	(P) p value
H1	BT → SC sustainability	0.15	0.09	0.06	.481	0.472
H2a	BT → SC integration	0.43	0.35	0.08	.347	.318
H2b	SC integration → SC sustainability	0.54	0.39	0.15	.081	.079
H3a	BT → SC mapping	0.58	0.51	0.07	.185	.162
H3b	SC mapping → SC sustainability	0.41***	0.28	0.13	.005	.007
H4	SC mapping → SC integration	0.33***	0.21	0.12	.004	.000

Note: WS: Welch-Satterthwait; P: Parametric.

*** $p < .01$ ** $p < .05$

instance, tracking and providing visibility through the entire supply chain optimize the information flow and generates cost reduction". Our findings empirical support this statement as we could observe significant positive influence of BT on SC integration and SC mapping. Our results support the central argument of the study that blockchain

technologies can play an instrumental role in promoting the supply chain mapping and integration, which further enhance SC sustainability. It illustrates that BT helps a firm coordinate and share the information with key supply chain entities in a timely, robust and trustworthy manner. BT not only improves the speed of this exchange but also

offers innovative and secured means of information sharing (Mahmood & Mubarik, 2020; Mubarik et al., 2020; Queiroz et al., 2019).

BT is essential for improving SC sustainability. It helps improve SC visibility, reduce errors, enhance response rate, identify human rights issues at tier 1 and tier 2 suppliers, and so on. However, the literature reports several challenges and barriers in adopting BT to improve SC sustainability (Kouhizadeh et al., 2021). First, data security, its accessibility will improve with time and maturity. Second, in order to achieve the maximum benefits of BT to enhance SC sustainability, top management commitment and understanding (Mougayar, 2016), organizational policies, communication, and building consensus among each partner in SC (Mangla et al., 2018; Oliveira & Handfield, 2019), and its culture is essential. Lastly, technology infrastructure at every stage of SC (Abeyratne & Monfared, 2016) and making sure that each stakeholder in SC has information and experience of BT (Gorane & Kant, 2015). Our study hypothesis, “H1: Blockchain technologies improve SC sustainability of a firm,” which was rejected, is in line with the barriers and propositions mentioned in the study of Kouhizadeh et al. (2021) and study by (Kamble et al., 2019). In addition, BT is a relatively new technology and not mature enough for the organization to get direct benefits to enhance SC sustainability. As time passes, organizations will start getting benefits by addressing barriers in adopting BT, understanding its challenges, and planning accordingly (Kouhizadeh et al., 2021).

BT can also play a significant role in providing real-time information about suppliers and customers. This ability of BT uplifts the SC integration, which further improves SC sustainability (Mubarik & Zuraidah, 2019; Queiroz et al., 2019).

Likewise, the prime focus of BT is traceability, which is the essence of SC mapping. BT allows a firm to map end-to-end its supply chain by connecting to tier 1 and tier 2 suppliers and customers. This channel integration allows real-time traceability of the flow and origin of the goods and material. In short, BT plays a central role in mapping the supply chain of a firm. Further, a well-mapped supply chain is traceable and visualized. This helps a firm to monitor and evaluate the supply chain processes from suppliers to customers. As a result, a firm can identify the non-sustainable processes and then can fix them accordingly. This greatly improves supply chain sustainability (Mahmood & Mubarik, 2020). Presently, firms are increasingly facing the issue of lack of transparency. It is not only raising the cost but also creating customer relationship management issues. Our findings show that BT can overcome this issue by providing provenance tracking through SC mapping. It allows all the players in the supply chain, including suppliers, customers, manufacturers, and couriers, to access the relevant information, further improving the trust between them (Mubarik & Zuraidah, 2019; Queiroz et al., 2019).

Our findings also show that BT improves real-time product tracking, significantly reducing the overall cost of moving an item in a supply chain. Further, by strengthening traceability, it improves the efficiency of SC mapping.

Owing to the innate complexities of the supply chain, it is becoming difficult for an organization to manage and develop effective collaboration for reducing supply chain risk. Furthermore, the multi-tiered nature of the supply chain, having participants from geographically dispersed areas, makes supply chain prone to various risks by reducing the integration. Our findings show that BT, by offering scalability through which any extensive database is accessible from multiple locations from around the world, improves the supply chain integration, further improving the supply chain sustainability (Mangla et al., 2020; Queiroz et al., 2019).

Putting together, “Blockchain is often explained as ‘one version of the truth’ for each product. It is a system of records aimed to capture proof of money transactions like bills of lading and money transactions. It covers all stages of the supply chain – from serialization and shipping to receiving and installation – each is tracked automatically. This system is built on principles of trust, transparency, and audibility.”

6 | IMPLICATIONS

6.1 | Managerial implications

This study provides some highly valuable and practical implications related to BT adoption. Our findings suggest that it is important for managers to consider the use of BT for aiding SC mapping, visibility, and traceability. This improves the overall supply chain integration and significantly reduces the risks of reputational losses by increasing the SC traceability. One major example is the *E. coli* (*Escherichia coli*) outbreak linked to the Chipotle Mexican Grill outlets, leaving dozens of customers ill. This led the stock prices to fall by up to 42% and caused substantial reputational losses to the company. The incident occurred due to two major reasons—first, the poor visibility and transparency across the supply chain of Chipotle. Second, due to the limited capability to monitor multiple suppliers in real-time. These obstacles further prevented Chipotle's from tracing the source of loss. The implementation of BT can significantly aid in overcoming such issues by enabling a firm to map the supply chain effectively.

Further, the BT-led-SC mapping can offer strong grounds to improve SC integration and SC sustainability (Christopher & Peck, 2004). The case of Tesco is a second major example in this regard. In 2013, the company lost nearly 300 million euros when horse meat was found in beef products at some of its stores. The complexity of its food supply chain, having various layers of suppliers, made it extremely challenging for Tesco to identify and separate the origin of the horse meat. The inability to do so led the company to staggering financial and reputational losses (Fletcher, 2013).

Since SC mapping helps managers visualize all three streams of SC further, it improves managers' ability to trace the origin, bottlenecks, and unsustainability in their SC processes. Further, it also allows managers to share relevant information across the supply chain

and collaborate with all the involved entities. BT not only provides traceability and security in the supply chain processes but it also, with the help of cutting-edge technologies, allows a firm to execute business transactions more effectively. Because of the increase in SC traceability and integration, and timeliness of the information, managers can track the real-time information regarding the flow of material and information. This can significantly help to manage the optimal levels of inventories, further reducing cost and increasing efficiency. In addition, the adoption of BT enables managers to trace and audit transactions made in their supply chains. This leads to a considerable reduction in the cost of recalls. The higher level of mapping and SC traceability can help managers to visualize the processes and their conformance to sustainable practices. It provides the ability to zoom in on the micro-processes, which are traditionally overlooked, to evaluate their sustainability.

Further, BT magnifies the inefficiencies in the micro part of the supply chain, allowing managers to adopt more robust, sustainable, and cleaner business processes. It is important to note that BT helps a firm develop SC integration and sustainability and plays a very instrumental role in controlling the supply chain losses and chaos. Putting together, we recommend firms adopt BT as a cornerstone strategy for improving supply chain mapping, integration, sustainability.

Nevertheless, the adoption of BT is a challenging task and cannot be an immediate step. Particularly with regards to SC mapping, the biggest challenge could be the ability of a firm to obtain real data spanning the supply chain. One of the solutions can be a macro-map, which helps the firm identify the depth and breadth of a supply chain at the industry level. It can serve as the basis for exploring more detailed mapping of concentrated areas. Further, the organization needs to develop a comprehensive technological adoption strategy. Creating such a strategy allows a firm to evaluate the suitability of the latest technologies for implementation in the organization. It also helps the organization to be perpetual to adopt contemporary technologies.

It is worth mentioning that the adoption of BT requires some prudent pace to avoid any significant setback. Specifically, firms should be cautious while sharing the data as there may be a chance of sharing competitive information with supply chain partners inadvertently. Even though BT indirectly improves SC sustainability, it is imperative to carefully introduce sustainability-conscious BT compliant with various environmental laws and regulations in a global market. Traditionally, simple financial matrices are employed to assess the suitability of any technological adoption. However, in the case of BT, we strongly advocate including its ability to map the SC and to contribute to the SC sustainability as the major criteria factors for the selection of BT (Bai & Sarkis, 2017).

In short, “blockchain technology has the potential to solve significant glitches in traceability and surveillance along the chain. It enhances efficiency across all operations of the flow of goods, information about the storage and shipping of raw materials, delivering finished products from one point to another, and more. The results are a greater collaboration, streamlined inventory management, better asset usage, and more.”

6.2 | Theoretical implications

The study also has some theoretical implications. First, based upon the GS theory, we model the association between BT and sustainability. Unfortunately, our results do not support this relationship. Nevertheless, the findings demonstrate the highly significant indirect impact of BT on sustainability. It implies that directly modeling the impact of BT on Sustainability without the inclusion of any significant mediator or moderator can be misleading. It also demonstrates that instead of the direct effect of BT on sustainability, BT strengthens the actors that lead toward SC sustainability.

Second, while studying the BT-SC sustainability dyad, it is also important to model the implementation barriers in the framework. The majority of the previous literature on blockchain-enabled supply chains did not theorize as to how the implementation barriers can intervene or interact in the interplay between BT and supply chain management. The majority of the study focused on adopting blockchain technology (see, e.g., Orji et al., 2020), rather than seeking to understand the barriers and challenges. Our findings imply that theories like transaction cost, technology acceptance model, theory of planned behavior, technology readiness index, and unified theory of acceptance and use of technology provide a strong theoretical basis to include the implementation barriers while studying the BT-enable supply chain sustainability (Kamble et al., 2019; Queiroz & Wamba, 2019).

7 | CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

The overarching objective of the study was to examine the impact of blockchain technologies on supply chain sustainability directly and through supply chain mapping and integration. By collecting data from 132 Malaysian E&E firms and applying PLS-SEM, the study found a significant indirect effect of BT on SC sustainability. The results were not significant in the case of the direct impact of BT on sustainability. The findings of the study lead us to recommend BT-led-SC mapping and SC integration as the critical organizational strategies for improving the SC sustainability of a firm. The findings also reveal that BT improves real-time product tracking, further significantly reducing the overall cost of moving an item in a supply chain. We therefore conclude and argue that the application of BT improves SC sustainability in many ways. For example, accurately tracing inferior merchandise and preventing the further exchange of the goods can help lessen product recall and rework for the organizations, which on the one hand, helps in reducing monetary losses while on the other, stops ozone-depleting caused by greenhouse emissions and bring efficiency in the consumption of resources (Saberli et al., 2019). Similarly, there is a central focus in the traditional power transmission processes, while a shared peer-to-peer network is required for enabling BT for energy processes. This reduces the need for transmission of power over extensive distances, ultimately sparing a significant bit of power resource wasted over significant distance transmission. It would also

contract the requirement for power stockpiling, which spares its assets.

As in other studies, this study has certain limitations. The first limitation of the study is the use of cross-sectional data. Since, the application of the BT is not very old. It is highly challenging to get longitudinal data on it. Nevertheless, the use of longitudinal data can reveal the true nature of BT-sustainability relationships and how it does evolve over the period. The second limitation of the study is the single country focus. The study takes the data of Malaysian firms for analyzing as to how BCT affect SC mapping and sustainability. Due to the unique development and technological readiness level, firms in other countries may not necessarily have the same business processes and readiness as Malaysian firms. Hence, a cross-country analysis may provide an in-depth analysis.

We will suggest future research studies to try to obtain longitudinal data to study the same model. The results can reveal an interesting picture. Second, the focus of the study on a single sector, the electrical and electronics sector of Malaysia, is another limitation. This sector has a comparatively higher tendency toward the adoption of BT. Other sectors like textile, furniture, leather, and so on, are much behind in terms of their orientation and intention to adopt BT. This focus on a single sector makes the generalizability of the results not only limited but also tenuous. The issue can be dealt with by taking the cross-industry data for analysis. We also suggest future research to compare and contrast the supply chain sustainability performance of firms with block chain technologies and those who do not. This will help to substantiate the claim made by this research and will pave the way to decide about the adoption of BCT for SC mapping and sustainability.

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How to cite this article: Khan, S. A., Mubarak, M. S., Kusi-Sarpong, S., Gupta, H., Zaman, S. I., & Mubarak, M. (2022). Blockchain technologies as enablers of supply chain mapping for sustainable supply chains. *Business Strategy and the Environment*, 31(8), 3742–3756. <https://doi.org/10.1002/bse.3029>