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The blockchain-enabled technology and carbon performance: Insights from early adopters

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ABSTRACT

This paper examined the drivers of blockchain technology adoption and carbon performance using the theory of technology-organization-environment (TOE) as the basis for the development of a technology adoption framework. Blockchain technology has passed the proof testing phase and is attracting early adopters who can gain benefits from it. Manufacturing firms that had adopted the blockchain technology and voluntary reported the carbon emission were targeted as the sample and survey data were collected from manufacturing firms that were registered with the Association of Malaysian Manufacturers. Unfavourable support of top management and the lack of technology competence were the main barriers to the adoption of blockchain technology among manufacturing firms. The results indicate that firms did not achieve low carbon performance and that a lack of pressure from competitors and technical competency to undertake blockchain technology were factors. No evidence existed demonstrating a linkage of early adopters of blockchain technology with and low carbon performance. Recommendations of this study include that firms should take the initiative to record the energy consumption, engage in the transfer of carbon credits, and monitor carbon performance using reliable technology to improve business transparency and sustainability.

1. Introduction

In the last four decades, Southeast Asia countries have transformed rapidly from agriculturally based nation to countries in which industry leads the economy. In Malaysia, without exception, the industrial sector has become a leading enabler of economic grown. Political stability, safety, proximity to vendors and consumers, among other reasons, have attracted global manufacturing firms to run their operations in Malaysia. Global manufacturing plants have established in the country and have begun to ramp up high-end technology to leverage their competitiveness, and cyber-physical production systems utilized in Industrial Revolution 4.0 have become critical for firms to gain a competitive advantage [1]. In this process, the Malaysian government has aided in attracting investors, taking responsibility for creating pro-active industrial regulations, clean energy incentives, digitalization of production and distribution. Additionally, pressure for cleaner production, transparency, accountability, automation, and lower cost production have to the promotion of blockchain technology in industry. Blockchain technology can be used to improve visibility, transparency and the accurate computation of the country's carbon footprint [2]. Blockchain technology has a high level of security and cannot be hacked. It can be used to support the integration of energy production, utilization, transmission, and storage [3] so that every carbon footprint activity and carbon trading transaction can be tracked and no data can be manipulated.

The supply chain of manufacturing firms is among the primary contributors to carbon emissions [4]. From a manufacturing perspective, energy consumption, logistics and waste are among the contributory factors of carbon emissions as is the transportation of finished goods [5]. Concern with low carbon performance drove the government to promote lower greenhouse gas emissions, with carbon dioxide (CO_2) serving as mitigation yardstick. To service this end, Malaysia had announced the intention to voluntarily reduce carbon emissions up to 40% by 2020 [6]. Unfortunately, Malaysia had increased projection CO_2 emissions by about 68.9% in 2020 compared to emissions produced in

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2000 [7]. Because emissions target and date could not be met, the target date was revised, with the government pushing to reduce greenhouse gases by 45% by 2030 [8]. Despite these good intentions, the likelihood of actually achieving the newly articulated emissions target and target date remains difficult if no initiation is taking to understand the performance measurements of carbon emissions. However, successfully monitoring and measuring carbon remains difficult.

As mentioned, this paper aims to investigate the drivers of blockchain technology adoption and carbon performance among early adopters. The behavioural perspective on the energy consumption will lead to better understanding of how effective the blockchain technology was adopted to enhance the industrial awareness of the sustainability issues.

The rapid industrialisation of the nation's economy has led to rapidly escalating energy consumption and an unprecedented rise in greenhouse gas emissions. In this context, CO_2 is classified as a greenhouse gas and is a by-product of the consumption of non-renewable fossil fuels like coal, petroleum and natural gas [4,9]. As the level of greenhouse gases has risen, climate change has become a central concern around the globe due to rising sea levels, sea surface temperature, the melting of Arctic sea ice and presence of extreme weather. However, manufacturing firms' actions towards climate adaptation have often been sorely underwhelming. Although various guidelines and policies exist for carbon emission reductions, the deliberations on the adaptation of strategies remain inadequate. According to Al Amin et al. [10], most developing countries have been left behind environmentally sustainable thresholds and, hence, have not succeeded in developing and following sustainable development strategies effectively, which include carbon reduction and the use of renewable sources of energy.

Manufacturing firms are facing pressure from stakeholders to submit carbon footprint reports in Malaysia. In December 2013, the Ministry of Natural Resources and Environment in Malaysia introduced the National Carbon Reporting Program (MyCarbon) to encourage Malaysian firms to report their carbon footprint voluntarily. Unfortunately, the initiative was fruitless. Industry provided little support from industry and data reported by the firms have the potential for manipulation or data loss. However, with the application of blockchain technology, fraud can be avoided due to the fidelity and transparency of blockchain technology.

Blockchain technology is currently receiving interest for a wide variety of industries [11] and has been proven to be a useful concept to improve the transparency and integrity data. Although industry has accepted blockchain technology, a need exists for further development to achieve the desired operational and target performance [12]. Malaysia has been looking to use blockchain technology in its predominant industries, especially in renewable energy and the palm oil and agricultural sectors. For example, the Malaysian electricity agency has taken a significant interest in blockchain technology because they believe that technology will encourage the faster adoption of renewable energy. The goal is the certification of palm oil sustainable supply chains using blockchain and distributed ledger technologies.

This paper differs from others based in terms of its contributions. The first contribution lies in its uniqueness. This paper is one of the early studies investigating the impact of blockchain technology adoption on achieving better carbon performance using TOE as underpinning theory. As little information available in literature on how the blockchain technology has been adopted in the industry. The question on what the main drivers of blockchain technology to achieve the better carbon performance remains unidentified.

The TOE is utilized to predict the drivers of blockchain technology adoption and among the expected outcomes of this paper is assisting scholars in understanding the critical drivers of blockchain technology and a way to move forward for improvement. The second contribution is the emphasis on how this new technology can be adopted successfully. The drivers would be insights for the best practices. Currently, blockchain technology has moved past the concept-testing stage and the process of deployment. The insight from early adopters can extend the proof concept of digitalization of manufacturing process and distribution. The outline of this paper is as follows. Section 2 briefly describes the adoption of blockchain technology and builds a theoretical framework using a review of the relevant literature. Section 3 discusses methods of measurement, data collection and sampling. Section 4 presents the results of the analysis, and a discussion of the findings is presented in Section 5. The paper ends with limitations and suggestions and for future studies.

2. Literature review

2.1. Blockchain technology

Blockchain technology can be defined as a distributed ledger that is cryptographically secure and immutable, in which changing the dada is extremely hard [13]. Blockchain enables each of the transactions without requiring the involvement of third parties. According to Laurence [14], in the blockchain system, each transaction made is recorded onto a ledger and then put into the block. Each block is connected with a block before and after it. Once a block is connected within a chain, it becomes immutable, and a single actor cannot alter or delete the blocks. Blockchain is a decentralization network that enables suppliers and demanders to make point-to-point transactions. All enterprise nodes will follow the same protocol.

According to Wang et al. [15], two types of blockchains exists, which are based on access control mechanisms. The first type is a public blockchain. This type of blockchain can make transactions without permission and is anonymous. A public network has an incentivizing mechanism to encourage more participants to join the network. The second type is a private blockchain. A member who wants to the join network needs to be invited or have system approval. Usually, a single organization (private blockchain) and a consortium of members' monitor access.

Bottlenecks, a shortage of talent, standardisation and supervision mechanisms and reliability and security issues are among the challenges of blockchain adoption [16]. If a firm can adopt blockchain technology, then they gain several benefits. The first benefit is disintermediation. In peer-peer networks, blockchains reduce reliance on third parties. Second, security is increased because the information and data that have been distributed are hard to hack. This is because the information recorded in the database is permanent and uses computational algorithms. Third, the blockchain provides transparency. Participants in a blockchain are unable to alter information, which reduces the possibility of avoiding fraud and dishonesty [15]. Thus, according to Janssen et al. [17], blockchain technology has been heralded as the next revolution of an effective business transaction.

2.2. Blockchain-enabled technology for carbon trading

As emissions have become a primary concern, manufacturing firms have received increasing pressure to limit the amount of greenhouse gas (GHG) of total production. Khaqqi et al. [18] postulated that blockchain technology could be used as a platform for emissions trading. An emissions trading scheme (ETS) is known as tradable permits policy. In this context, an equal number of GHS permits are distributed to firms. At the end of a defined period, participants are required to issue a report on the amount of emissions produced. Then, participants can trade their GHG permits. A firm that has produced less GHG than permitted can sell their excess capacity to others who have produced more emissions than permitted.

An ETS can assist manufacturing firms in achieving carbon emissions reduction. The transparency and fidelity of emission trading process using blockchain technology can improve efficiency, transparency and fidelity [19]. Carbon trading using blockchain technology can ensure the safety of each transaction. All transactions will be faithfully recorded in a shared ledger, and a timestamp record will ensure that each transaction can be traced back. Blockchain technology can record and transmit information flow in carbon emission trading to avoid lost quotas or repeated transactions. Any unauthorised trading activity will be detected. All carbon emission transactions must comply with the same consensus algorithm to make all processes consistent [20].

2.3. The energy consumption and blockchain related environmental impacts

The blockchain technology drives the efficiency in the control and manage the energy consumptions. The mining algorithms need to be utilized to cluster the pattern of energy consumption and sustainability. The support of AI and virtual energy management systems are able to indicate the optimal placement of heat recovery in a distributed ledger of blockchain technology [21]. Besides, the Internet of Things can be installed to support the blockchain and monitor the energy consumption in real time. It will assist the authorized personnel to access the transparent and reliable data of energy consumption. The energy consumption data recorded from Blockchain can be visualized. It can be identified which energy are produced from renewable and nonrenewable resources [22]. Yet, it is timely to discuss the sustainability issues in the application of blockchain technology from behavioral and socio-economic perspectives [21]. From a technical point of view, Parnell [23] posit that the scholar should able to solve the grid stability to monitor the energy usage in the blockchain systems. The bitcoin can track and visualize unsustainability of the energy consumption with algorithm. Despite that the Bitcoin as the platform of the blockchain technology can work effectively and monitor the electricity consumption [24], it has been argued that Bitcoin gains doubt due to its scalability and sustainability of the technology [25]. The success adoption of blockchain technology can reduce the negative impact on environmental outcomes such as fossil fuel combustion. In nutshell, blockchain technology can promote the development of renewable energy and meets the aim of global carbon reduction [26].

2.4. Technology, organizational and environmental model

TOE framework is used to explain the adoption of blockchain technology. Tornatzky and Fleischer [27] developed the TOE, which provides an integrative framework for the adoption of emerging technology. TOE categorised three distinguish contexts. First is the technological context. It addresses the variables of the technologies that influence decisions about blockchain technology adoption, like technical competence and compatibility. Second is the organizational context. This context describes the variables of an organization that influence blockchain technology adoption, such as firm size and top management support. The third, and last domain, is the environmental context. This context explains the variables related elements that surround an organization, such as competitive pressure.

There are other variables available in the literature on theory adoption model, and most of the theory adoption models were relevant to individual users and not applicable to the corporate perspective (e.g. Technology Acceptance Model, Theory of Reasoned Action, Unified Theory of Acceptance and Use of Technology, etc.). From corporate perspective, TOE has guided the scholars to identify the drivers of technology adoption. The domains of TOE are extended from time to time to ensure the relevancy of the theory to timely business context. In this paper, we have adopted the TOE drivers to predict the technological adoption.

2.5. Carbon performance

CO_2 is the most abundant greenhouse gas that human activities produce. Because carbon emissions are the largest greenhouse gas emissions, monitoring CO_2 is critical as is consistently determining whether emission targets are met. According to IPCC [28], manufacturing is the second-largest contributor to carbon emissions at 21% behind energy generation at 25%. Manufacturing firms should focus on reducing carbon emissions of products, using energy efficiency and reducing the usage of carbon-intensive materials to lower carbon emissions [29]. Low-carbon performance can be monitored using a composite indicator. This indicator is an analytical tool to summarize complex and multi-dimensional low-carbon performance [30]. Governments can educate firms to practice clean production and provide incentives to lower their carbon footprints.

3. Hypothesis development

The three factors that are considered the drivers of blockchain technology adoption are the technological context, organizational context, and the environmental context. These drivers have been conceptualized to predict blockchain technology adoption among manufacturing firms. The adoption of blockchain technology can assist a firm in achieving low-carbon performance. Fig. 1 shows the research model.

3.1. Technological-organizational-environmental and blockchain technology adoption

The technological context refers to the technologies relevant to a firm. This includes technology competence and compatibility. Technological competence indicates the preparation of a firm in infrastructure, as well as the level of knowledge relating to such technology, and a firm's willingness to become involved in the familiarization of such an activity [31]. The firms with sufficient resources are more competent to adopt blockchain technology because they are better prepared than incompetent ones (H1).

Compatibility is an essential factor in explaining innovation usage by organizations and is the extent to which innovation is seen to be consistent with the needs of an organization. High compatibility has been identified as a facilitator for innovation implementation (H2). Therefore, compatibility may be a critical determinant of blockchain technology adoption [32].

The organizational context describes the characteristics of an organization. Common organizational characteristics include firm size, readiness, and top management support. Firm size can influence the adoption of blockchain technology. For example, large firms have more resources than small firms [33]. If not ready for the adoption of a new technology, a firm potentially faces risks associated with compatibility. It has been argued that the large scale firms are faster than small firms for new technology adoption due to availability of resources (H3).

Top management support plays a vital role in the adoption because blockchain adoption involves new regulatory requirements, the

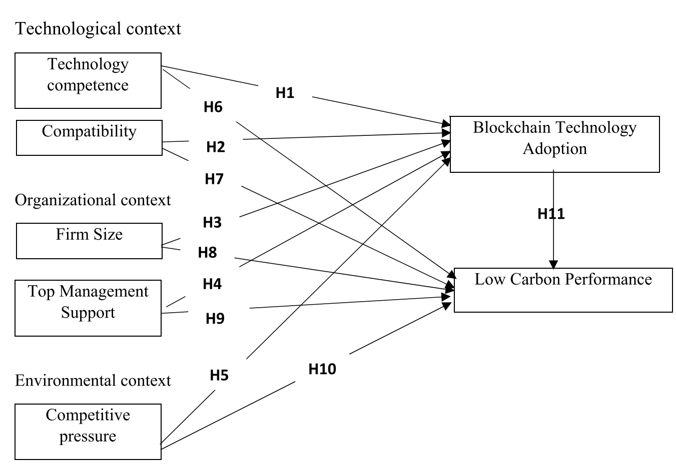


Fig. 1. Research model.

acquisition of new resources, a high degree of complexity, information exchanges, the integration of resources, competencies and the development of new skills [34–36]. Top management has designed strategic business plans and is responsible for business performance. They have an important role to suggest the appropriateness of technology adoption to improve overall business performance (H4).

The environmental context is the industry in which a firm conducts its business and the perceived competitive pressure in the industry. Competitive pressure refers to the pressure from competitors that a firm feels to adopt new technology and has been found to be an essential driver for technology diffusion. From lens of industrial behavioural perspective, the companies are willing to adopt new technology when their competitors are already used it. They are aware that technology can help them be more economical to establish a competitive edge (H5).

The adoption of new technology is often a strategic necessity to compete in the marketplace [33]. By adopting blockchain technology, firms can have better market visibility and more accurate access to real-time data. These propositions can be morphed into the following hypotheses:

H1. Technology competence will have a significant and positive relationship to the adoption of blockchain technology.

H2. Compatibility will have a significant and positive relationship to the adoption of blockchain technology.

H3. Firm size will have a significant and positive relationship to the adoption of blockchain technology.

H4. Top management support will have a significant and positive relationship to the adoption of blockchain technology.

H5. Competitive pressure will have a significant and positive relationship to the adoption of blockchain technology.

3.2. Technological-organizational-environmental and carbon performance

According to Ritter and Gemunden [37], technology competence enables an organization to use, understand and exploit technology internally. Also, technical competence supports the preparation of technology infrastructure, including the adoption of a basic level of knowledge as it relates to the available technology. Firms which are competence on the technological adoption will be able to perform better on the carbon outcomes (H6).

In terms of compatibility, rather than manually record data for carbon emissions, the implementation of blockchain technology can help in reducing fraud, manipulation and data loss. We argued that the compatible technology adopted by firms on energy consumption will lead to low carbon performance (H7).

The size of the firm is associated with the firm's total assets, which reflects a firm's resources. Higher sustainability value can be found in larger firms, and such firms tend to deliver more environmental metrics in their annual reports [38]. On the other hand, without government support, small-sized firms are mostly challenged by insufficient budgets for complying with energy-related regulations. Since the blockchain technology has lead to the carbon monitor and reduction, the government has invested initial capital for technology adoption. The large and small size companies have equal opportunities to achieve low carbon performance (H8).

Top management support is a determining factor in organizations, which controls all processes, including decision making and strategic planning [39]. The firms will run their business well if the top management supports the adoption of emerging technology to achieve low carbon reduction (H9).

Lastly, firms are increasingly subject to competitive pressure to reduce GHG emissions in a country that is committed to reducing carbon emissions. Pressure for low carbon performance can be achieved if the company has observed that competitors have better carbon performance than them (H10). These statements can be morphed into the following hypotheses:

H6. Technology competence will have a significant and positive relationship with carbon performance.

H7. Compatibility will have a significant and positive relationship with carbon performance.

H8. Firm size will have a significant and positive relationship with carbon performance.

H9. Top management support will have a significant and positive relationship with carbon performance.

H10. Competitive pressure will have a significant and positive relationship with carbon performance.

3.3. Blockchain technology adoption and carbon performance

A lack of enforcement on environmental compliance can no longer be ignored [40]. Firms need to invest in the technology to comply with environmental regulations and assume responsibility for reducing carbon emissions, and blockchain technology is a reliable platform to record and transmit information flow in carbon emissions trading. According to Pan et al. [20], blockchain technology can be deployed to record corporate carbon transactions. Firms can visualize carbon emission activities and record carbon performance. The consumption status will be checked at specified intervals, and the output of carbon emissions reduction will be stored in the database. Thus, the adoption of blockchain technology can help a firm to avoid fraudulent transaction records with a timestamp and a unique cryptographic signature. The transparency and integrity of GHG can assist a firm to achieve low carbon performance.

H11. Blockchain technology adoption has a significant and positively related to carbon performance

4. Methods

An electronic survey collected data from a sample of manufacturing firms listed in the FMM 2019 directory (n = ±3194 firms). A few filtered questions were utilized as sample inclusiveness criteria and avoid the selective bias issues such as 1) to ensure whether the company has adopted the technology under investigation; 2) to ensure whether the company has been actively monitoring energy consumption for last three consecutive years; 3) to ensure that carbon performance has been reported and discussed in the annual general meeting. If these three criteria are met, the company is asked to participate in the survey voluntarily.

This study addressed the e-survey to managing directors, IT managers, energy managers and production managers to target the appropriate decision-makers in a firm. Of the 500 questionnaires sent using stratified sampling, a total of 103 were returned, representing a response rate of 20.6%. Data retrieved from e-survey were analysed using IBM SPSS Version 23 (descriptive) and the structural equation modelling with PLS-SEM Software 3.2.8 for model and hypothesis testing. The PLS-SEM was utilized to ensure the data quality that meets the statistical requirements. PLS-SEM achieves the objective of study to investigate the relationship variance between independent variable and dependent variable. Convergent and discriminant validity tests were utilized to ensure the goodness of the model exist in the model and a bootstrapping procedure for hypothesis testing.

After the data were collected, the first step was to examine the completeness of the data, code and label the data and sorting error entries such as missing or incorrect values and recoding some relevant variables. The variables were measured using a questionnaire that contained 29 construct items. Each measurement item was measured using a 5-point Likert scale to help respondents express their level of agreement or disagreement with each statement. Likert scale values ranged from 1 (strongly disagree) to 5 (strongly agree). The instrument items were adapted from the previous studies (See appendix).

5. Results

5.1. Profile of Manufacturing's firm

The descriptive analysis was conducted to identify the profile of the respondents. Table 1 shows that no significant disparities were identified between early (1-week after initial invitation) and late (follow up after 1-week) survey responses. The late response participants are proxy of the non-response ones. The non-respond bias test was established. Thus, no evidence was found for response bias ($p > 0.05$).

Table 2 shows the profiles of the firms. Questions such as firm size, ownership and frequency of monitoring carbon emissions were asked to know the background of the firm. Most firms had more than 200 employees with (48.5%), followed by 75–200 employees at (38.8%) and of 5–75 employees (12.6%). Furthermore, the ownership most of the participating firms were Malaysian owned (31.1%), followed by joint venture at 27.2%, American-based firm at 21.4%, followed by Asian and Europe at 10.7% and 9.7% respectively. Finally, the frequency of firms monitors carbon emission were quarterly at 49.5%, monthly at 21.4%, semi-annually at 19.4% and annually at 9.7%. This study only selected firms that had adopted blockchain technology to understand how this technology was relevant to lowering carbon emissions. Table 2 shows that manufacturing firms that had initiated adopted blockchain technology less than 10% (80.6%) of deployment (early adopters). Most participating firms provided training for blockchain technology to employees (63.1%), while only 36.9% did not provide training for employees.

5.2. Common method bias

Common method bias can occur when the respondents falsely answer questions. Bias could happen because one person represents a firm. Because the possibility existed that common bias could occur in the model, a collinearity test was performed to ensure all analysed data were free any of method biases. VIF is generated for all latent variables in a model. According to Hair et al. [41], the VIF value should be lower than 5 to be an acceptable score. All VIF scores were lower than 5, ranging from 1.660 (lowest) to 3.403 (highest), which indicates that they are free from common method bias.

5.3. Model measurement

5.3.1. Convergent validity and reliability

Convergent validity can be measured using outer loadings of each construct, average variance extracted (AVE) and composite reliability (CR). The accepted value for outer loadings should be greater than 0.5 to meet the reliability and validity criteria [41]. Based on Table 3, all reflective items were retained and had an acceptable value (>0.5). Second, convergent validity is acceptable when the average variance extracted (AVE) exceeds 0.5 [42]. Table 3 shows that all AVE values were more than 0.5, which indicates that measurement constructs explained half or more of variance in indicator variables. The values ranged from 0.688 to 0.927. Cronbach's alpha can be used as a traditional criterion for internal consistency. It provides an estimate of the reliability based on the inter-correlations of the observed indicator variables. CR is used as a suggested replacement of the traditional criterion because CR gives a more accurate estimation. Hair et al. [41] suggested that value for CR should be 0.7 and above. Table 3 shows that the CR values for all constructs were higher than the benchmark of 0.70.

Table 1
Non-response bias results in terms of main constructs.

	Response	Mean	Std. Deviation	Std. Error Mean	p-value
T	Early	3.4643	1.13127	0.42758	$p > 0.05$
	Late	3.2448	1.12155	0.11447	
CP	Early	3.3214	1.10599	0.41802	$p > 0.05$
	Late	3.5547	1.03632	0.10577	
FS	Early	3.2857	0.78004	0.29483	$p > 0.05$
	Late	3.5972	1.06614	0.10881	
TM	Early	3.2000	1.27541	0.48206	$p > 0.05$
	Late	3.5271	0.95327	0.09729	
CPP	Early	3.0000	0.90139	0.34069	$p > 0.05$
	Late	3.5156	0.99724	0.10178	
BTA	Early	3.2500	0.85391	0.32275	$p > 0.05$
	Late	3.6953	0.96054	0.09803	
LCP	Early	3.2571	1.14143	1.14143	$p > 0.05$
	Late	3.2917	1.01148	1.01148	

Table 2
Firm demographic profile.

Demographic	Categories	Overall	
		Frequency	Percent (%)
Firm size (Number of employees)	5–75	13	12.6
	75–200	40	38.8
	>200	50	48.5
Ownership	Malaysia	32	31.1
	Joint venture	28	27.2
	Europe	10	9.7
	Asian	11	10.7
	American	22	21.4
Monitor carbon emission	Monthly	22	21.4
	Quarterly	51	49.5
	Semi annually	20	19.4
	Annually	10	9.7
Level of blockchain technology deployment	<10	83	80.6
	10–25	20	19.4
Internal training provided	Yes	65	63.1
	No	38	36.9

Table 3
Convergent validity.

Construct	Item	Loadings	CR	AVE	Cronbach's Alpha	VIF
Blockchain Technology Adoption	BTA1	0.897	0.930	0.770	0.900	2.950
	BTA2	0.906				
	BTA3	0.877				
	BTA4	0.828				
Compatibility	CP1	0.879	0.938	0.791	0.912	3.403
	CP2	0.894				
	CP3	0.866				
	CP4	0.918				
Competitive pressure	CPP1	0.877	0.899	0.690	0.850	2.974
	CPP2	0.769				
	CPP3	0.874				
	CPP4	0.798				
Firm Size	FS1	0.960	0.974	0.927	0.960	2.754
	FS2	0.961				
	FS3	0.966				
Low Carbon Performance	LCP1	0.792	0.934	0.738	0.911	2.130
	LCP2	0.834				
	LCP3	0.883				
	LCP4	0.897				
	LCP5	0.885				
Technology competence	T1	0.913	0.946	0.813	0.923	2.158
	T2	0.907				
	T3	0.930				
	T4	0.855				
Top Management Support	TM1	0.835	0.917	0.688	0.886	1.660
	TM2	0.862				
	TM3	0.870				
	TM4	0.759				
	TM5	0.816				

5.4. Discriminant validity

Discriminant validity can be assessed through Fornell and Larcker criterion, cross-loading and HTMT ratio to ensure that construct items are dissimilar from other construct items. According to Hair et al. [43], the square root of AVE of a latent variable should be greater than the correlations between the latent variable and all other variables. Table 4 shows that the Fornell and Lacker criterion indicates that the square root of each variable was higher compared to other below constructs value. The cross-loadings can be established to perform a discriminant validity. Table 5 shows each of the loadings of an item assigned on its latent variable was higher than the loadings on other latent variables. However, Fornell-Larcker criterion as cross-loadings assessment was unable to capture discriminant validity criteria. Thus, an additional validity test using the Heterotrait-Monotrait (HTMT) criteria was required. According to Gold et al. [44], value for HTMT should be below 0.9 for reflective indicators. Table 6 shows that all HTMT values were below 0.9, and the highest of HTMT statistics was 0.849, which is lower than the threshold value of 0.850.

5.5. Hypothesis testing

R-square (R^2) is the coefficient of determination and quantifies the explanatory power of predictors on the criterion. According to Hair et al. [41], the rule of thumb for the categories is: R^2 is 0.25 for weak, 0.50 is for moderate, and 0.75 is for substantial. The calculated R^2 value of TOE drivers was 0.651, meaning that 65.1% of low carbon performance variance could be attributed to TOE and blockchain technology adoption. Meanwhile the R^2 of blockchain technology adoption was 0.661, suggesting that 66.1% of blockchain technology adoption could be explained by TOE theory.

Table 7 shows the results of hypothesis testing. The corresponding t-values were used to show the significance of the relationship between the constructs, and a 5% significance level ($p < 0.05$; t-value > 1.645) used as the basis of acceptance decision criterion. Seven of the eleven hypotheses were accepted, and four hypotheses were rejected. H1 examined whether technology competence had a positive and significant relationship with blockchain technology adoption. Technology competence had no significant relationship with blockchain technology adoption because the t-value was 0.162, which was less than 1.645 and coefficient value = −0.018, so hypothesis H1 was rejected.

H2 examined whether compatibility had a positive and significant relationship with blockchain technology adoption. A significant and positive relationship existed between competitive pressure with blockchain technology adoption (t-value = 3.072, coefficient value = 0.366), so H2 was accepted. H3 examined whether firm size had a positive and significant relationship with blockchain technology adoption. The results found that this relationship was statistically supported because the t-value was 2.157, which was more than 1.645 at a 5% significant level and coefficient = 0.274, so H3 was accepted. H4 examined whether top management support had a positive and significant relationship with blockchain technology adoption. The results found no relationship because the t-value was 0.650, and H4 was rejected. Hypothesis H5 examined whether competitive pressure had a positive and significant relationship with blockchain technology adoption. The results found that the relationship was statistically supported because the t-value was 3.025 and coefficient was 0.325, so H5 was accepted.

Table 4
Fornell & Larcker criterion.

Construct	BTA	CP	CPP	FS	LCP	T	TM
BTA	**0.878**						
CP	0.727	**0.889**					
CPP	0.743	0.719	**0.831**				
FS	0.693	0.632	0.708	**0.963**			
LCP	0.458	0.613	0.502	0.557	**0.859**		
T	0.572	0.679	0.587	0.631	0.356	**0.902**	
TM	0.452	0.582	0.485	0.535	0.765	0.386	**0.829**

Note: BTA = Blockchain Technology Adoption; CP = Compatibility; CPP = Competitive Pressure; FS = Firm Size; LCP = Low Carbon Performance; T = Technology Competence; TM = Top Management Support.

Table 5
Cross - loading.

	BTA	CP	CPP	FS	LCP	T	TM
BTA1	**0.897**	0.604	0.678	0.656	0.342	0.556	0.306
BTA2	**0.906**	0.624	0.641	0.582	0.362	0.438	0.352
BTA3	**0.877**	0.665	0.702	0.651	0.422	0.503	0.416
BTA4	**0.828**	0.654	0.582	0.537	0.477	0.507	0.509
CP1	0.628	**0.879**	0.595	0.546	0.487	0.710	0.476
CP2	0.618	**0.894**	0.609	0.549	0.534	0.626	0.505
CP3	0.664	**0.866**	0.687	0.549	0.550	0.537	0.511
CP4	0.673	**0.918**	0.662	0.601	0.601	0.555	0.570
CPP1	0.657	0.629	**0.877**	0.618	0.466	0.560	0.341
CPP2	0.531	0.520	**0.769**	0.525	0.377	0.365	0.354
CPP3	0.692	0.643	**0.874**	0.627	0.481	0.495	0.530
CPP4	0.573	0.590	**0.798**	0.577	0.324	0.523	0.372
FS1	0.647	0.609	0.668	**0.960**	0.528	0.610	0.508
FS2	0.687	0.634	0.713	**0.961**	0.541	0.626	0.553
FS3	0.665	0.581	0.662	**0.966**	0.539	0.586	0.482
LCP1	0.467	0.463	0.378	0.439	**0.792**	0.369	0.631
LCP2	0.286	0.531	0.397	0.429	**0.834**	0.295	0.628
LCP3	0.411	0.547	0.509	0.481	**0.883**	0.285	0.644
LCP4	0.388	0.557	0.453	0.514	**0.897**	0.266	0.675
CP5	0.423	0.529	0.415	0.523	**0.885**	0.327	0.705
T1	0.512	0.613	0.511	0.598	0.372	**0.913**	0.349
T2	0.462	0.568	0.517	0.560	0.289	**0.907**	0.340
T3	0.456	0.568	0.471	0.539	0.269	**0.930**	0.278
T4	0.601	0.673	0.596	0.566	0.337	**0.855**	0.403
TM1	0.465	0.463	0.436	0.429	0.603	0.345	**0.835**
TM2	0.397	0.526	0.390	0.446	0.616	0.306	**0.862**
TM3	0.348	0.544	0.363	0.433	0.639	0.395	**0.870**
TM4	0.330	0.393	0.327	0.413	0.583	0.220	**0.759**
TM5	0.332	0.480	0.480	0.491	0.721	0.325	**0.816**

H6 examined whether technology competence had a positive and significant relationship with low carbon performance. A significant and positive relationship existed between technology competence with low carbon performance (t-value = 2.009, coefficient value = 0.171), H6 was accepted. H7 examined whether competitive pressure had a positive and significant relationship with low carbon performance. The results found that this relationship was statistically supported because the t-value was 2.778 and coefficient value = 0.322, H7 was accepted. H8 examined whether firm size had a positive and significant relationship with low carbon performance. The results found that the relationship was significant, with a t-value of 2.185 and a coefficient value = 0.213. H8 was accepted.

H9 examined whether top management support had a positive and significant relationship with low carbon performance. The results found that the relationship was statistically supported. The t-value was 6.215 and coefficient was 0.564; thus, H9 was accepted. H10 examined the relationship between competitive pressure and low carbon performance; the t-value of the path was 0.162 and coefficient value = 0.015, so H10 was rejected. H11 examined whether blockchain technology adoption had a positive and significant relationship with low carbon performance. Because the t-value 0.880 and coefficient value = −0.092, H11 was rejected.

5.6. Importance-Performance Map analysis

According to Ringle and Sarstedt [45], Importance-Performance Map (IPMA) can be applied to study the performance level between manifest variables and latent variables. Besides, IPMA provides information on the importance of variables to targeted construct. IPMA can be used to give more effort to the low latent variable that is required further to managerial actions. It can be used to analyse the indicator level to identify critical activities for the improvement of the dependent

Table 6
Heterotrait-Monotrait (HTMT) ratio.

Construct	BTA	CP	CPP	FS	LCP	T	TM
BTA							
CP	0.800						
CPP	0.843	0.813					
FS	0.744	0.674	0.781				
LCP	0.507	0.670	0.563	0.594			
T	0.617	0.736	0.653	0.666	0.386		
TM	0.505	0.644	0.551	0.579	0.849	0.418	

Note: BTA = Blockchain Technology Adoption; CP = Compatibility; CPP = Competitive Pressure; FS = Firm Size; LCP = Low Carbon Performance; T = Technology Competence; TM = Top Management Support

Table 7
Hypothesis testing.

Hypothesis	Path	Std Beta	Std Error	t-value	p-value	5.00%	95.00%	f	R	Q	Decision
H1	T - > BTA	−0.018	0.112	0.162	0.436	−0.198	0.155	0.000	0.661	0.624	Rejected
H2	CP - > BTA	0.366	0.119	3.072	0.001	0.173	0.552	0.131		0.595	Accepted
H3	FS - > BTA	0.274	0.127	2.157	0.016	0.080	0.468	0.087		0.722	Accepted
H4	TM - > BTA	−0.057	0.088	0.650	0.258	−0.201	0.089	0.006		0.509	Rejected
H5	CPP - > BTA	0.325	0.107	3.025	0.001	0.150	0.516	0.117		0.466	Accepted
H6	T - > LCP	0.171	0.085	2.009	0.023	0.310	0.038	0.039	0.651	0.624	Accepted
H7	CP - > LCP	0.322	0.116	2.778	0.003	0.109	0.488	0.088		0.595	Accepted
H8	FS - > LCP	0.213	0.097	2.185	0.015	0.019	0.349	0.047		0.722	Accepted
H9	TM - > LCP	0.564	0.091	6.215	0.000	0.414	0.699	0.549		0.509	Accepted
H10	CPP - > LCP	0.015	0.094	0.162	0.436	−0.132	0.173	0.000		0.466	Rejected
H11	BTA - > LCP	−0.092	0.105	0.880	0.190	−0.261	0.086	0.008		0.566	Rejected

variable. Table 8 shows that low carbon performance and technology competence were among the lowest constructs. This is indicated that firms were still challenged in achieving low carbon performance and lacked technical competency. Firms are continuously digitalizing supply chain networks using blockchain technology to remain competitive. In fact, blockchain technology adoption was the highest construct in the model. (Fig. 2).

IPMA was established to identify which manifest variables have good performance and are of importance to the targeted construct. The results of IPMA for BTA shown in Table 9 indicate that item CP4 had the highest performance with (66.505) and a high importance level with (0.110) to the blockchain technology adoption while item T3 had the lowest performance (53.155) with low importance level (−0.004). The values of importance level ranged from −0.015 to 0.111 while values of performance range from 53.155 to 66.505. Table 10 shows the results of IPMA for LCP, which indicate that item BTA3 had the highest performance with (68.204) but had the low importance level with (−0.028) to the low carbon performance while item FS3 had the lowest performance (53.155) with a high importance level (0.065).

Table 8
Latent variable index values and performance on constructs of low carbon performance.

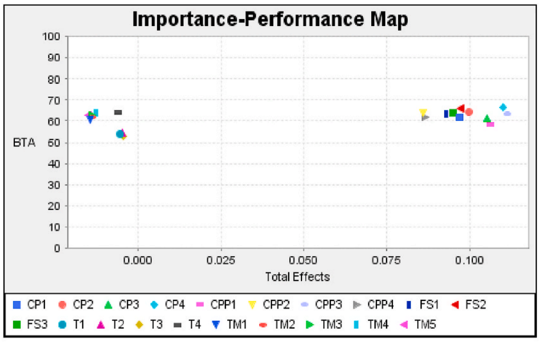
	LV Index Values	LV Performances
Blockchain Technology Adoption	3.664	66.608
Compatibility	3.539	63.466
Competitive pressure	3.477	61.930
Firm size	3.574	64.356
Low carbon performance	3.296	57.409
Technology competence	3.295	57.364
Top management support	3.506	62.641

6. Conclusion and policy implications

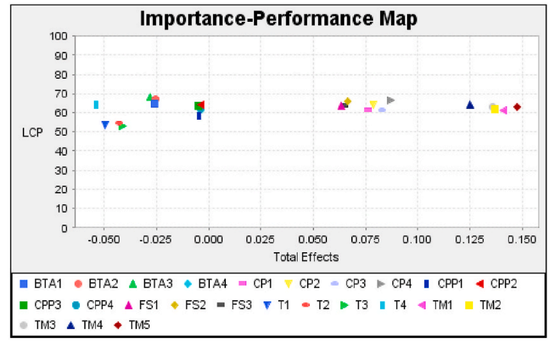
To understand the drivers of new technology adoption among manufacturing firms for blockchain technology and carbon performance, this study proposed TOE theory to support the theoretical framework. The aim was to understand how the effective usage of emerging technology to avoid the loss or manipulation of carbon emission data and progression of a way forward on the Industrial Revolution 4.0 movement in Malaysia. The current record of footprint data was unable to track carbon trading and reporting correctly. Conventional reporting with human intervention will be replaced by blockchain technology to monitor the performance of GHG emission at the firm level. The digitalization efforts will support the current certification programme on emission reduction (CERs) and renewable energy (RECs). However, not all firms have initiated the adoption of blockchain or frequently monitor their carbon performance.

Regarding technology adoption drivers, the findings are consistent with the Oliveira et al. [33] that highlighted that the compatibility of technology, firm size and competitive pressure were among the critical drivers of adoption. Large-sized firms with enough resources will have the opportunity to recruit more skilful, experienced and knowledgeable operation/IT/energy managers to support the adoption of new technology. Also, firms can outsource vendors to develop blockchain technology to record their carbon emission activities and cater necessary training to the employees.

This study found that competitive pressure had a direct link with the adoption of blockchain technology, which supports the findings of Missi et al. [46]. The higher the competitive pressure from competitors, the more likely a firm is to adopt blockchain technology to improve its competitiveness. A firm is more likely to seek ways of achieving sustainable competitive advantage through effective and innovative technologies, which, in turn, will distinguish them in the industry. However, the absence of top management support and technology competence can



a) Importance-Performance Map (indicator level) on target construct of blockchain technology adoption



b) Importance-Performance Map (indicator level) on target construct of low carbon performance

Fig. 2. Importance-performance Map (indicator construct) on the target construct of blockchain technology adoption and low carbon performance.

Table 9
Indicators' importance and performance of TOE theory to the targeted construct blockchain technology adoption.

Item	CP	CPP	FS	T	TM
1	0.097* (61.650)**	0.086 (64.078)	0.093 (63.350)	−0.005 (53.888)	−0.014 (60.922)
2	0.099 (64.320)	0.086 (64.078)	0.097 (66.019)	−0.005 (54.612)	−0.014 (61.893)
3	0.105 (61.408)	0.111 (63.592)	0.095 (63.835)	−0.004 (53.155)	−0.014 (63.107)
4	0.110 (66.505)	0.087 (61.893)		−0.006 (64.320)	−0.013 (64.078)
5					−0.015 (63.107)

Note: Values in parentheses are indicators' performance. * Importance level (Total effect), ** Performance.

Table 10
Indicators' importance and performance of TOE theory and blockchain technology adoption to the targeted construct low carbon performance.

Item	BTA	CP	CPP	FS	T	TM
1	0.026* (64.563) **	0.076 (61.650)	0.005 (58.495)	0.063 (53.888)	0.014 (60.922)	0.141 (60.922)
2	0.025 (66.990)	0.079 (64.320)	0.004 (64.078)	0.066 (54.612)	0.014 (61.893)	0.137 (61.893)
3	0.028 (68.204)	0.083 (61.408)	0.005 (63.592)	0.065 (53.155)	0.014 (63.107)	0.136 (63.107)
4	0.026 (66.748)	0.087 (66.505)	0.004 (61.893)		0.013 (64.078)	0.125 (64.078)
5					0.015 (63.107)	0.147 (63.107)

Note: Values in parentheses are indicators' performance. * Importance level (Total effect), ** Performance.

be barriers to the adoption of blockchain technology, which is consistent with the findings of Wang et al. [26]. Blockchain technology was mostly introduced by start-up firms that offer their service to the clients. Unfortunately, these early adopters are often not competent to manage the new technology to control low carbon performance. Besides, top management is still not giving much support for the adoption and national regulations for reporting carbon emissions (MyCarbon). It is still based on voluntary efforts. If top management does not give full support for adoption, the rest of the effort will remain merely an intention. Top management should not only invest in t infrastructure but also in establishing technical knowhow of blockchain technology itself for a smooth-sailing operation.

The results indicate that drivers like technology compatibility and competence, firm size, and top management support were significantly and positively related to low carbon performance. However, a direct positive link from blockchain adoption to low carbon performance remained insignificant. A firm has an obligation to study carefully the supporting factors of blockchain adoption to improve carbon performance. Firms must find environmentally friendly technology to balance the demands of sustainability and fulfilling consumers' desires and green requirements [47]. Based on the findings of this study, the blockchain is still not the primary choice and ideal platform yet to record the transactions of purchasing carbon credits, carbon emission savings, monetizing carbon credits and carbon performance report until the enforcement to comply carbon emission activities with credible, accountable and transparent, and auditable technological platform.

Since 2013, Malaysia has started to promote carbon emissions reporting and initiated a voluntary pilot carbon disclosure programme for industry. Because a good response has not been achieved from industry for reporting carbon performance, the time is ripe to examine the implementation of these programme at the corporate level. Although firms have mentioned carbon emissions in their annual report or annual sustainability and corporate responsibility reports, the actual data of carbon emission remains challenging to capture. In the current stage, the government agency is still exploring the potential drivers and incentive to attract more companies to adopt blockchain technology and involved actively in the transformation of renewable energy. The finding from the early study to test the proof of concept is needed. It can be utilized as the basis to design a policy to enhance the development of the industry and society's well-being. In the future, the government needs to enforce the company to declare the transparency on how the energy was generated and spent. The blockchain technology can be a good platform for carbon trading on the excess the electricity generated from their solar farms and its distribution.

Out of 72 countries have reported the finding of blockchain technology, China has lead the global movement of blockchain technology and its impact on the energy research followed by the United States, the United Kingdom, Italy and India [26]. However, the findings remain without consensus on what drives the company the most to adopt the blockchain technology. It is because most of the studies have reported the findings from experimental analysis and country perceptive. Lack of sociodemographic and corporate perspective domains were tested to draw a conclusion on blockchain technology adoption and its impact to their energy outcomes.

This study limited itself to the perception of respondents of carbon performance. Future study should use actual carbon performance data because actual data will provide a better understanding of a firm's achievements. It will assist top management in designing strategic planning, which with emissions reduction activities. The future study is also needed to explore the technical attributes of blockchain technology to be used to monitor the corporate GHG emission performance. Although this model has been tested in Malaysia, the future study can extend and test it in different country settings and find the consensus on the drivers and outcomes. Different country settings might produce different results. It is interesting to observe how the impact of blockchain technology has been adopted to reduce carbon footprint with different energy policy, incentive, socioeconomic factors and resources. In summary, future study could examine the impact of low carbon emission on financial performance.

This study is based on the early adoption of blockchain technology among manufacturing firms in Malaysia. From an energy management perspective, blockchain adoption could be used to monitor GHG performance, especially from the production and transportation activities. The blockchain technology adoption is still not well practised in monitoring carbon reduction. Firms will adopt the technology to monitor carbon emission activities if the government provides incentives. The drivers' adoption of blockchain technology and low carbon performance were identified, but the connection between blockchain technology adoption and low carbon performance remain without evidence. This is because the blockchain adoption remains in its initial stage and firms are still learning about its features and the necessary investments. Industry needs more exposure to the technology that enables them to be ready for the Industrial Revolution 4.0. Technical know-how is another issue that needs to be solved. Firms need to understand the clean energy requirement technology to comply with environmental regulations and to remain sustainable over the long term.

Declaration of competing interest

We do not have conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techsoc.2020.101507.

Appendix

Measurement of instruments items:
Technology competence
i) Our firm technology infrastructure is available to deploy blockchain technology
ii) Our employees are familiar with blockchain-related technology
iii) Our employees have a sufficient level of blockchain technology-related knowledge.
iv) Our people have adequate skills to implement blockchain technology
Compatibility
i) Blockchain technology is compatible to support our business operation.
ii) We use blockchain technology as a best practice in industry.
iii) Blockchain technology fits with our firm's work culture.
iv) Blockchain technology is used in our firm based on the principle of business transparency.
Firm size
i) Our firm's capital is higher compared to others in the industry.
ii) Our firm's revenue is higher compared to others in the industry.
iii) Our firm has more competence employees compared to others in the industry.
Top management support
i) Our top management provides enough support for blockchain technology initiatives.
ii) Our top management is willing to take risks (financial & organisational) for new technology deployment.
iii) Our top management provides enough resources for blockchain technology.
iv) Our top management understands the benefits of blockchain technology.
v) Our top management looks at blockchain technology as strategically important.
Competitive pressure
i) Our firm is under pressure from competitors to deploy blockchain technology.
ii) Some of our competitors have already started using blockchain technology.
iii) Our firm thinks blockchain technology adoption influences competition in industry.
iv) We will have had a sustainable competitive advantage if we deploy blockchain technology.
Blockchain technology adoption
i) It is a feasible/viable option to adopt blockchain technology.
ii) Our firm can foresee the business potential for the utilization of blockchain technology.
iii) Our firm had utilized blockchain technology to support our business.
iv) Our firm is very likely to continue to use blockchain technology.
Carbon performance
i) Our firm has managed to reduce the usage of carbon-intensive materials (per unit of output).
ii) Our firm has managed to reduce carbon emissions in its operation (per unit of output).
iii) Our firm has reduced energy use (per unit of output).
iv) Our firm has reduced its overall carbon emissions.
v) Our firm has reduced fees/fines/taxes paid for carbon emissions discharge.

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