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Research article

Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms

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ABSTRACT

Background: The current level of industrialization has generated many challenges worldwide, including ecological hazards, climate change, and the overuse of non-renewable natural resources, thereby creating an increasing demand for achieving the goal of the Triple Bottom Line (TBL). In this regard, Industry 4.0 can be used as a crunch point to contribute to the production process that can help achieve sustainable development.

Purpose: While the Malaysian government proposed the "Industry4ward" approach to enhance technological adoption, there is scarce empirical evidence in the literature that validates SMEs for Industry 4.0. Using Dynamic Capability View (DCV), this study proposes a framework that includes core determinants like top management commitment, supply chain integration, and IT infrastructure, that can significantly influence Industry 4.0 implementation toward achieving TBL sustainability.

Design/methodology/approach: Employing simple random sampling, the study adopted a quantitative approach based on 199 useable respondent's feedback collected through a survey questionnaire of 900 employees from Malaysian SMEs. The statistical analysis was performed using Structural Equation Modeling (Partial Least Square, SmartPLS 3.3.2).

Findings: The results show that top management and IT infrastructure significantly impact Industry 4.0 implementation and sustainability. In contrast, the analysis also demonstrates that supply chain integration is insignificant to Industry 4.0 implementation in SMEs. The findings also indicate that the relationship between the determinants of Industry 4.0 and TBL sustainability can be mediated by the "effective implementation" of Industry 4.0.

Recommendations: The study highlights the practical consequences of the role and use of the determinants in Industry 4.0 implementation. Its findings help managers and policy-makers to optimize value creation to achieve sustainable development goals.

Limitations and future research: Focusing only on Malaysian manufacturing SMEs may restrict the generalization of the study; thus, a benchmarking analysis from other industrial settings is encouraged. The questionnaire-based survey is a further limitation of the study.

1. Introduction

Industry 4.0 is a means of industrial transformation that introduces new technological prowess by integrating information technologies and automation that communicate among themselves to achieve optimum performance (Kamble et al., 2018; Queiroz and Telles, 2018). Societies have great concern for achieving sustainable development because of the rapidly growing population, resource depletion, environmental pollution, land scarcity, increased food demand, and waste management (Furstenau et al., 2020). The challenges call for reviewing sustainability practices, standards (Wood et al., 2015), measurement methods (Waas et al., 2014), and emerging technologies. Such issues are encouraging organizations to develop new ways of production and consumption to ensure sustainability. The organizations are being evaluated based on both economic as well as sustainability performance (Furstenau et al., 2020). In this regard, Industry 4.0 offers a tremendous opportunity for

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firms to achieve sustainability (Stock and Seliger, 2016). It is a futuristic and multifaceted process that has many opportunities and challenges (Zhou et al., 2016). It allows organizations to self-organize, diagnose, and act on real-time issues, as well as optimize and enhance the system's capability to learn and adapt in a dynamic environment (Tran et al., 2019; Yang et al., 2018). Accordingly, organizations are rapidly embracing emerging technologies and manufacturing methods to transform, capture, share, and interpret data from production tools and other autonomous systems (Sarvari et al., 2018). The digital revolution allows organizations to become more efficient by adopting the latest technologies in the production system. Thus, Industry 4.0 provides a competitive advantage by producing quality products at a lower cost (Makris et al., 2019) and ensures the efficient use of non-renewable resources.

Industry 4.0 is the integration of the production system with advanced industrial technologies, thus, allowing them to communicate with others and act in real-time without human intervention and allows organizations to produce smart products and services (Buer et al., 2018). Oughton et al. (2019) highlighted that technological transformation such as Industry 4.0 and other related technologies are crucial for societal and economic development and it depends on digital connectivity. Nevertheless, while Industry 4.0 and financial performance-related research has been growing, a limited number of research has addressed the scopes and barriers that may affect Industry 4.0 and sustainability (Kiel et al., 2020). Additionally, the concept is at its pre-paradigmatic stage and is rapidly evolving; hence, it requires continuous investigation for ensuring its contribution to the "Triple Bottom Line" (economic, ecological, and societal) perspective (Varela et al., 2019). Thus, scholars illustrate the scarcity of studies in this field and call for additional empirical research (Kipper et al., 2020; Liao et al., 2017). Researchers emphasize the importance of Industry 4.0 to ensuring sustainability (Kamble et al., 2018; Müller et al., 2018). Recent studies (Garbellano and Da Veiga, 2019; Gupta et al., 2020) have analyzed the role of dynamic capabilities in implementing Industry 4.0 to attain sustainability. Longo, Nicoletti, and Padovano (2017) and Díaz-Chao et al. (2020) demonstrate the importance of taking action to build capabilities. Organizations need to possess certain capabilities that ensure proper implementation of Industry 4.0. Yet, the literature addressing the key determinants of Industry 4.0 that act as capabilities and strengthen sustainability has not articulated the missing links between the determinants and sustainability (Akhtar et al., 2020). However, while technically evident, there have been very little empirical studies regarding the role of the determinants in implementing Industry 4.0 and sustainable practices (Díaz-Chao et al., 2020). The literature in this area is scarce in relation to the context of emerging economies. Hence, this study focused on the role of the key determinants of Industry 4.0 and how they contribute to implementing Industry 4.0 for sustainable production processes in manufacturing SMEs.

Considering the above research issues, this study examines how the determinants of Industry 4.0 affect manufacturing SMEs' Industry 4.0 implementation to achieve the Triple Bottom Line (TBL) sustainability. SME firms are relatively less integrated within the global value chain and have a focus on the local market. The three core influential determinants, top management commitment, IT infrastructure, and supply chain integration and their impact on Industry 4.0 implementation leading to economic, environmental, and social sustainability is the fundamental focus of this study. Therefore, the study deals with the following research questions.

Q1. Do the determinants (top management commitment, supply chain integration, and IT infrastructure) influence the "effective implementation" of Industry 4.0?

Q2. Does the "effective implementation" of Industry 4.0 contribute to achieving TBL sustainability?

Q3. Does the "effective implementation" of Industry 4.0 mediate the relationship between the determinants of Industry 4.0 and TBL sustainability?

This study provides valuable insights for SMEs, as the TBL sustainability research is still insignificant in emerging countries considering the relationships between the SMEs' capabilities and Industry 4.0 implementation. The SMEs have limited resources for implementing Industry 4.0 despite their huge role in the national economy. Hence, the study brings to light the core determinants that are necessary to conduct business for a sustainable future. The study demonstrates that the determinants significantly influence Industry 4.0 implementation among Malaysian SMEs. The determinants allow organizations to embrace the latest technologies and enable organizations to understand the issues and concerns surrounding automation and reinforce the implementation of Industry 4.0.

The sequence of the paper is structured as follows: Section 2 portrays the literature review, the theoretical background accompanied by hypotheses formulation is illustrated in Section 3. Section 4 and 5 demonstrate the research methodology, data analysis, and results respectively. Section 6 summarizes the main findings with discussion, the significance of the study, limitations, and future study directions. Final remarks are presented in the conclusion.

2. Literature review

2.1. Malaysian SMEs and sustainability

Yusoff et al. (2018) suggested coming up with an integrated model of SMEs and sustainable achievements by considering internal organizational factors to attaining sustainable growth. According to the Malaysian New Economic Model (NEM), sustainability indicates the achievement of present-day objectives "without compromising future generations by effective stewardship and preservation of the natural environment and non-renewable resources." They indicate that SMEs and their sustainable growth interchange as financial self-sufficient growth through the performance without endangering their long-term survival. TBL is frequently used as a substitute for sustainability (Alhaddi, 2015). From the organizational perspective, it encourages the adoption of new technologies and concepts to accomplish the social, economic, and environmental goals termed as the triple bottom line (Montabon et al., 2016).

SMEs' contribution to the Malaysian economic growth is ample and realizing this fact, the Malaysian government has introduced several programs to enhance sustainable performance (Musa and Chinniah, 2016; Yusoff et al., 2018). The Department of Statistics Industrial Production Index (IPI) has increased to 26 % in manufacturing indices and its sales increased to 37.2 % (Department of Statistics, 2021). The micro, small, and medium categories are depicted in Figure 1.

Based on sustainable development goal-9 (industry, innovation, and infrastructure), Malaysia encourages sustainable industrialization and the country wants to increase the industry's share in employment by 2030. The vision and mission of Malaysian SMEs are to pursue a path of excellence and sustainability, and reads as follows: "The premier organization for the development of progressive SMEs to enhance wealth creation and social well-being of the nation"; "Promotes the development of competitive, innovative and resilient SMEs through effective coordination and provision of business support." Recent statistics show that SMEs are the backbone of the Malaysian economy, as 98.5 % of business establishments are from the SME sector. Therefore, the government of Malaysia is encouraging SMEs to adopt and implement Industry 4.0 to attain a competitive advantage and remain sustainable.

2.2. Industry 4.0 and its implementation

Industry 4.0 was conceptualized as the fourth revolution that has arisen in the manufacturing industry, yet this conceptualization has evolved during the past few years (Xu et al., 2018). Industry 4.0 involves the digital transformation of the entirety of industrial and consumer

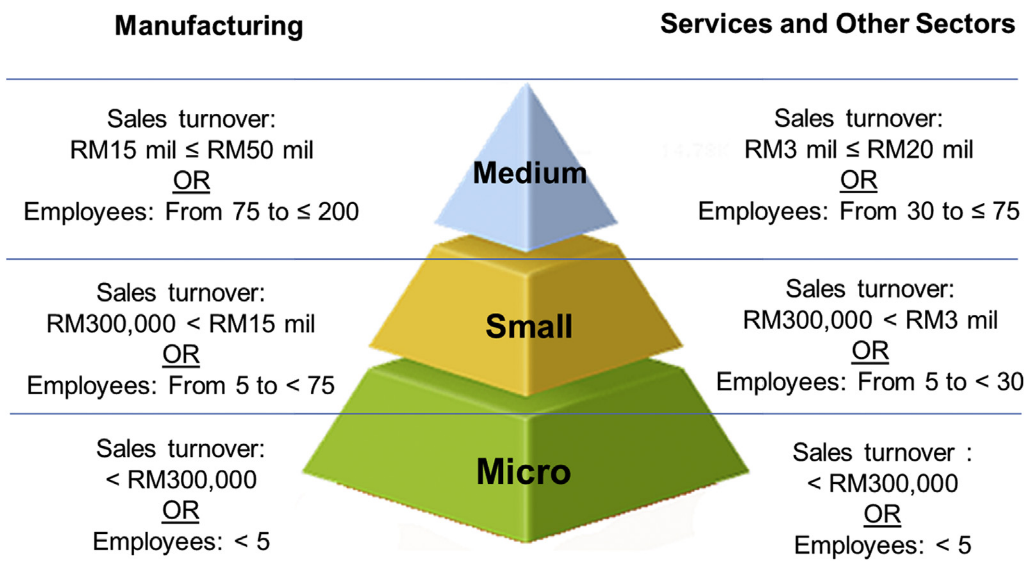

Figure 1. SMEs contribution in Malaysian economy.

markets, from the advent of smart manufacturing to the digitization of the entire value delivery channels (Schroeder et al., 2019); this has been unanimously recognized by the industry, academia, and government (Ghobakhloo, 2020). Industry 4.0 facilitates the smart factory (Chen et al., 2018; Longo et al., 2017), where physical systems can be connected among themselves as well as with human beings in real-time, enabled by the Internet of Things (IoT) (Morrar et al., 2017). To achieve its underlying design principles, the digital revolution of Industry 4.0 relies on the implementation and integration of technologies like IoT, big data, cloud computing, and so on (Castelo-Branco et al., 2019; Frank et al., 2019; Sreenivasan et al., 2019). Many of these technologies were available to Industrialists during the past four decades (Chen et al., 2018; Gilchrist, 2016). However, they are very recently coming to maturity in terms of integrability and interoperability necessary for digitization (Ghobakhloo, 2020). The execution and implementation of Industry 4.0 is a complicated activity that consists of vertical, horizontal, and end-to-end integration (Wang et al., 2016). Horizontal integration facilitates partnership between organizations, especially in the value chain (Foidl and Felderer, 2015; Pérez-Lara et al., 2020). Through digitization, a new resourceful, adjustable, and self-advancing ecosystem is created (Sony, 2018). Vertical integration tends to integrate different hierarchical sub-systems creating an accommodating, active, and resourceful manufacturing system (Pérez-Lara et al., 2020; Vaidya et al., 2018). The end-to-end integration in the value chain facilitates the formation of tailor-made products (Stock and Seliger, 2016). Product and safety data-like routine problems, enhanced quality systems, as well as solutions and auto regulating and monitoring of already defined quality attributes through the implementation of the three integrations in Industry 4.0 can be tactically used to minimize the quality and safety aspects (Jayashree et al., 2021; Li and Lau, 2017; Sony and Naik, 2019b).The degree of adopting all the three kinds of integration in IR 4.0 implementation will lead to the achievement of competitive advantage when compared to their rivals (Sony and Naik, 2019b).

2.3. Triple Bottom Line (TBL) sustainability

After the "Brundtland report," (UN, 1987) there has been an increased awareness in society regarding the manufacturing industry and its impact on the environment (Kiel et al., 2020). From a sustainability perspective, apart from profit-making, stakeholders and their interests were also given due importance (McWilliams et al., 2016) resulting in several corporate social responsibility measures in the organizations (Paz et al., 2021). Sustainability has drawn global interest and attention because of its meaningful suggestions and solutions especially regarding the environment and changes in climatic conditions (Khan et al., 2021). Economic sustainability focuses on profit achievement (Schulz and Flanigan, 2016); social sustainability aims at the advancement of mankind and society (Kiel et al., 2020) and environmental sustainability strives to preserve natural resources (Bai et al., 2020). All three interact and in order to avoid conflict, a progressive relationship is expected within the TBL. In order to achieve sustainability, all three dimensions are crucial (Evans et al., 2017) and it has to be included in the organizational strategy (Schulz and Flanigan, 2016).

2.4. Industry 4.0 technologies and TBL sustainability

Industry 4.0 and sustainability are popular organizational trends that are vital to increasing sustainable production (Bai et al., 2020). Industry 4.0 technologies create a foundation to face the challenges arising from intense competition, fluctuating market demands, customizations, and the short span of the product life cycle (Telukdarie et al., 2018), and contribute significantly to the sustainable development of the society (Reza et al., 2020). Industry 4.0 technologies include substantial contributions to organizational and social sustainable development (Stock and Seliger, 2016). Economic aspects help to decrease set-up times, labor cost, lead times, and enhances organizational profit (Bai et al., 2020; Frank et al., 2019; Haseeb et al., 2019; Yong et al., 2020). From the environmental perspective, these technologies help to minimize energy consumption (Khan et al., 2021), minimize waste, increase energy savings (Yadav et al., 2020; Zhu et al., 2008), and encourage reuse and recycling (Kumar et al., 2020). From a social sustainability perspective, digital and smart technologies protect the health and safety of workers by minimizing boredom and repetitive tasks, which motivates employees and increases their job satisfaction (Müller et al., 2018; Yong et al., 2020). In order to utilize the resources efficiently, organizations should adopt environmentally-friendly Industry 4.0 technologies for sustainable production practices (Ghobakhloo, 2020). Therefore, the adoption and implementation of Industry 4.0 will support the Malaysian SMEs to remain competitive and contribute to the sustainable development goals for the nation.

3. Theoretical background

Teece et al. (1997) proposed dynamic capabilities to understand how successful organizations orchestrate and reconfigure organizational resources in search of perpetual competitive advantage in an era of rapid market dynamisms (Qaiyum and Wang, 2018). The theory stems from the firm's resource-based view (RBV) and connects the capabilities to distinguishable procedures and competitive practices that managers should synthesize to analyze their resources and incorporate them together, creating novel applications and higher value-addition (Teece, 2018). The conceptualization of dynamic capabilities is a complex task as they do not inherently reflect a single mechanism (Akhtar et al., 2020). Dynamic capabilities are different from the organization's ordinary capabilities (Karimi and Walter, 2015; Qaiyum and Wang, 2018), which require the reconfiguration of existing resources to attain the expected outcome. Scholars outline dynamic capabilities as an organization's capacity to transform and adapt the current resource through utilization and exploration. The internal organizational factors within the dynamic capability research serve as a foundation for developing dynamic capabilities (Álvarez and Torrecillas, 2020; Bendig et al., 2018; Kevill et al., 2017; Roy and Khokle, 2016). In particular, the dynamic capabilities view concludes that it is insufficient to achieve competitive advantage at a given point in time; rather the resources and capabilities must be reassigned, reconfigured, and modified to cope with the market dynamism ensuring continuous competitive advantage (Teece, 2007; Teece et al., 2009).

The determinants of Industry 4.0 such as top management commitment, IT infrastructure, and supply chain integration can be considered as examples of dynamic capabilities (DC) of the firms. These determinants imply that DC is a foundation by which the SMEs in emerging economies operate their business activities to remain competitive and sustained (Cepeda and Arias-Pérez, 2019; Ghobakhloo and Fathi, 2020; Gupta et al., 2020). At the same time, the determinants influence the structure and execution of business patterns. Dynamic capabilities produce business patterns that are crafted, refined, implemented, and transformed (Teece, 2018). Dynamic capabilities supported by operational routines and management expertise enable the firm to incorporate, build, and reshape existing competencies, resolve changes in the market climate, or even to achieve those changes (Teece et al., 2009). Dynamic capabilities comprise both soft and hard skills that the organization possesses to orchestrate organizational resources in a meaningful way that ensures sustainability. Additionally, Teece (2007) further clarifies dynamic capabilities through a framework of sensing, seizing, and transforming. The author claims that developing dynamic capabilities is the transforming or reconfiguring of resources in a meaningful way that might sustain firms' competitiveness, rather than analyzing and optimizing the current resource base. DC can encompass both financial, human, and strategic capitals. Researchers have revealed that the determinants act as the dynamic capabilities to implement Industry 4.0 competently that enable SMEs to achieve the sustainable development goals. Lin et al. (2020) demonstrated a framework showing the determinants as dynamic capabilities that enable organizations to implement Industry 4.0 successfully. Focusing on the DC view, Díaz-Chao et al. (2020) and Felsberger et al. (2020) showed how the determinants or the resources of the organizations enable them in capabilities building to implement Industry 4.0 in the dynamic environment rewarding sustainability. This study aims to explore the following determinants: top management commitment, supply chain integration, and IT infrastructure. These determinants are designated as the dynamic capabilities in Industry 4.0 implementation, and thus act as the crunch point in attaining sustainability among the Malaysian SMEs.

3.1. Top management commitment

Top managers play important roles in organizing business activities and developing sustainable business models, policies, and strategies. The accomplishment of any strategic changes of a firm requires enthusiastic supports from the top management (Sony et al., 2019). Accordingly, Industry 4.0 requires involvement and support from top management (Sony, 2018). In the Industry 4.0 context, financial and strategic guidance within the firm are influenced by the top management (Sony and Naik, 2019a). In fulfilling the specific expectation, the top management needs to have a practical understanding of the fundamentals of Industry 4.0 in order to redesign the managerial function to combine the vertical, horizontal, and end-to-end integration (de Sousa Jabbour et al., 2018; Sony and Naik, 2019a). Helfat and Peteraf (2014) found that top managers who are attentive and perceptive are more likely to recognize the emerging transformative changes. Roy and Khokle (2016) revealed that top management could help firms become familiar and acknowledge any change that occurs and systematically integrate all of the information. Top management needs to be very responsive to understand the firm's goals and objectives for incorporating Industry 4.0 technologies and sustainable industrial methods into the current production system, which in turn contributes to manufacturing transformation (de Sousa Jabbour et al., 2018; Shao et al., 2017). Competent management must commit to allocating adequate capital to accomplish the firm's mission (Tzempelikos, 2015).

Hermano and Martín-Cruz (2016) claimed dynamic capabilities require focusing on two main areas: the ability to redesign the firm's capabilities in light of the changing business environment and the top management's ability to adapt, integrate, and reconfigure the resources and capabilities to cope with the market dynamism. Researchers opined that top management is a resource allocator as well as an influential administrator who promotes organizational transformation to achieve its vision and actively participate in updating the structures, planning, organizing, directing, coordinating, regulating, setting of goals, leadership styles, resource allocation, and so on (Sony and Naik, 2020). Thus, Teece (2007) demonstrated that top management is involved significantly in building firm-level dynamic capabilities and this can be true in the case of Industry 4.0 research (Garbellano and Da Veiga, 2019).

At the same time, Burki et al. (2019) argued that the function and impact of top management's commitment are essential in attaining sustainability. Likewise, Wijethilake and Lama (2019) illustrated top management commitment as one of the vital capabilities for sustainable practices. Latan et al. (2018) demonstrated that eco-friendly practices in the manufacturing sector require organizational involvement, including the capability and responsibility of top management and green strategies. Conscious top management encourages green practices to be incorporated in the production process (Latan et al., 2018). Hence, the hypothesis H1 can be illustrated as the following:

H1a. There is a significant relationship between top management commitment and the "effective implementation" of Industry 4.0.

H1b. There is a significant relationship between top management commitment and TBL sustainability.

H1c. "Effective implementation" of Industry 4.0 mediates the relationship between top management commitment and TBL sustainability.

3.2. Supply chain integration

Supply chain integration defines the extent to which an organization collaborates with its supply chain partners, customers, and suppliers to achieve optimal integration of the physical, information, and financial flows (Huang and Huang, 2019; Zhang et al., 2015). Organizations can achieve a competitive advantage by integrating functional systems and operations to enhance the suppliers' and customers' relationships with the organizations (Bruque Camara et al., 2015).

The smart technologies of Industry 4.0, such as IoT, cloud computing, and big data enable organizations' data sharing, improved collaboration, and interoperability, resulting in advanced supply chain integration and logistics management (Macaulay et al., 2015). These technologies offer organizations effective supply chain collaboration among partners, including transport providers, suppliers, and customers, providing higher efficiency, liquidity, and flexibility with lower costs (Oztemel and Gursev, 2020; Winkelhaus and Grosse, 2020). Employment of smart technologies in the supply chain delivers warehousing amenities, joint warehousing, logistic, and inventory management on a real-time basis allowing organizations to deal with real-time paradigms (Ben-Daya et al., 2019; Cuzzocrea et al., 2020). Furthermore, smart technologies streamline an organization's efficient ordering and transportation, providing competitive supply chain integration (Ben-Daya et al., 2019). IoT promotes transparency and improves supply chain integration, including planning, packaging, and order picking (Bag et al., 2020; Francisco and Swanson, 2018). Big data analytics supports the development of logistics services, information handling, collaboration in the supply chain, employee skills, creativity, and operational decision-making proficiency to add value and money (Queiroz and Telles, 2018; Winkelhaus and Grosse, 2020). Cyber-physical systems and big data enable organizations to develop such capabilities to obtain full advantages of advanced supply chain integration toward building competitive advantage and sustainability (Bag et al., 2020).

Furthermore, the use of IoT and big data in the supply chain helps in understanding and accessing customer demand in real-time, enabling organizations to develop product quality and design (Kerin and Pham, 2019). These technologies allow companies to respond immediately to customers' requirements, build solid relationships, collaborate with supply chain partners, improve the capability to real-time forecasting, and monitor threats in the supply chain (Marinagi et al., 2018). Once the organization integrates the supply chain with Industry 4.0 technologies, it offers numerous advantages, including agility, versatility, efficiency, and accessibility in the supply chain management, improving the firms' competencies (Winkelhaus and Grosse, 2020). Therefore, scholars identified supply chain integration as a dynamic capability and precious resource, developing organizational competencies to remove challenges in business strategies (Bag et al., 2020). Researchers demonstrated that an automated and integrated supply chain improves the productivity and smooth circulation of the production process and enhances the overall sustainability of the supply chain. Thus, firms can employ Industry 4.0 technologies to enhance supply chain capabilities, enabling them to create sustained advantage. The above discussion supports the following hypothesis (H2):

H2a. There is a significant relationship between supply chain integration and the "effective implementation" of Industry 4.0.

H2b. There is a significant relationship between supply chain integration and TBL sustainability.

H2c. "Effective implementation" of Industry 4.0 mediates the relationship between supply chain integration and TBL sustainability.

3.3. IT infrastructure

IT is a connector as well as an enabler. IT infrastructure is fundamental in setting up Industry 4.0. It is developed as a vital component that is required to organize assets in improving business strategy and operational procedures in an Industry 4.0 environment (Mikalef and Pateli, 2017; Tang et al., 2020). Scholars found that IT infrastructure positively affects firm performance leading to greater efficiency. Additionally, IT infrastructure help firms create and use inimitable capabilities (Karagoz & Akgun, 2015), leading to improved firm performance and thus generating profits by reducing costs. Furthermore, IT infrastructure enables firms to diversify their products, leading to a higher revenue earning while implementing Industry 4.0. Advanced IT systems improve operating efficiency, competitiveness, and profits by acquiring essential resources such as patents (Erkmen et al., 2020). IT-based developments and inventions allow the creation of a sustainable source of productivity for firms. Smart technologies enable firms to build enhanced perceived firm performance and capabilities resulting in improved productivity (Akram et al., 2018). As the Dynamic Capabilities View suggests reconfiguration of capabilities in a meaningful way to create core competencies and competitiveness (Helfat and Peteraf, 2014; Teece, 2007), firms planning to adopt and implement Industry 4.0 need to transform their existing IT infrastructure by employing the latest technologies; this transformation will serve them to be sustainable and competitive, simultaneously (Autenrieth et al., 2018; Teece, 2007).

Prior research showed that IT infrastructure can affect firm productivity, but there is little coherence to clarify how IT executes such transformations (Mikalef and Pateli, 2017). However, researchers remarked that organization's IT infrastructure could bring success if properly utilized and some studies revealed how success can be achieved (Autenrieth et al., 2018). As the manufacturing system in Industry 4.0 is very complex and challenging (Roblek et al., 2016), the appropriate IT infrastructure for the firms intending to implement Industry 4.0 should be further examined. Therefore, it is essential to build an appropriate IT infrastructure that combines the sophisticated tools, techniques, and technologies used in the manufacturing system. Researchers also suggest incorporating some elements in the IT infrastructure that collect and sort abundant information related to Industry 4.0, such as connectivity between sensors and networks, cloud computing, CPS, content and context, interaction among the involved partners, and customization (Fedorov et al., 2015; Ji et al., 2016).

Most analytical studies consider IT infrastructure as three major types of resources, namely Technical IT, Managerial IT, and Human IT infrastructure. Managerial IT infrastructure are a set of foresight, market experience, and IT expertise that allow IT managers to maximize useful IT efforts; for example, improved IT infrastructure and reduced IT costs leading to economic sustainability (Erkmen et al., 2020). IT management skills are an essential basis of social sustainability due to their socially complex existence and the learning curve linked with their growth (Widodo, 2015). As a firm's strategic resource, technical IT infrastructure is an integral part of the IT resource (Garrison et al., 2015). Therefore, the hypothesis H3 can be formed as follows.

H3a. There is a significant relationship between IT infrastructure and the "effective implementation" of Industry 4.0.

H3b. There is a significant relationship between IT infrastructure and TBL sustainability.

H3c. "Effective implementation" of Industry 4.0 mediates the relationship between IT infrastructure and TBL Sustainability.

3.4. Conceptual framework

Figure 2 illustrates the conceptual framework. The framework exhibits the hypothesized relationships between the determinants of Industry 4.0, its effective implementation, and TBL sustainability among SMEs.

4. Methodology

This research aims primarily to examine the impact of the determinants of Industry 4.0 for its successful implementation to attain sustainable development goals. The study considered three important capabilities, namely top management commitment, supply chain integration, and IT infrastructure. The research (Figure 2) shows the determinants of Industry 4.0 enabling firms to achieve sustainability through successful implementation of Industry 4.0.

The discussion on the research design started with the population, unit of the study, and sampling design. Then the measures consisting of designing, structuring, and scaling of the survey questionnaire are presented. The study adapted all the validated measurement items from existing literature; therefore, the questionnaire achieved a suitable reliability and validity level.

4.1. Measurements

The researchers created a questionnaire with a 5-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (5). The study adapted all the measurement items from existing literature with slight or

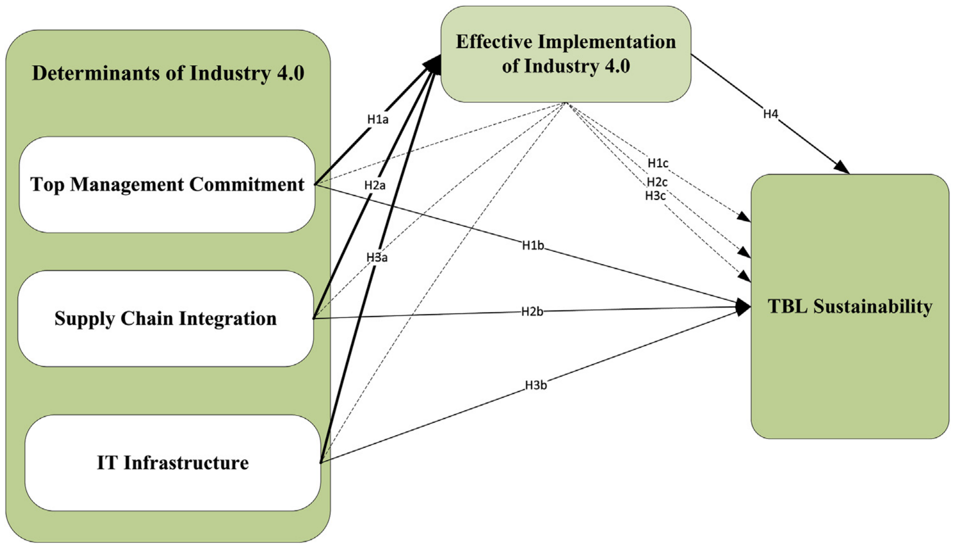

Figure 2. Conceptual framework.

complete modifications. Table 1 shows the constructs/items used in the research questionnaire.

4.2. Sampling and data collection

The study selected organizations (SME) as the unit of analysis and the targeted respondents were SME managers. Simple random sampling was employed in this study. According to Xu et al. (2004), SME managers clearly understand their organizations and provide reliable information. Additionally, a manager knows better about their organization's goals and cultures; therefore, the response would represent the organizations' appropriate perceptions (Hassan et al., 2017).

The SMEs in the manufacturing sector were selected for data collection, and the list of the companies along with the mailing and e-mail address was obtained from the Federation of Malaysian Manufacturers (FMM), Malaysia. Then, SMEs that are highly technologically integrated were identified. The authors contacted to these SMEs to find the targeted managers for getting responses from them. Once the managers were identified, they were contacted via e-mail, phone calls, and personal visits. A total of 900 questionnaires were sent to the SMEs' managers, and 206 were returned with seven incomplete questionnaires; the incomplete questionnaires were omitted from the analysis. The initial response rate was 23 %; however, after excluding the unusable questionnaires, the valid responses were 199, and the valid response rate was 22 %. Thus, for the data analysis, 199 responses were used.

5. Data analysis and results

Initially, the missing value, outlier, mean, median, standard deviation, and normality assumptions were obtained through a preliminary analysis using SPSS version 22. As the research is exploratory, it contains formative constructs and aims to define the significant capabilities (Ramayah et al., 2018) of SMEs in the implementation of Industry 4.0; therefore, the study employed Partial Least Square (SmartPLS 3.3.2) to analyze the data. The statistical analysis is presented in the following sections.

5.1. Descriptive statistics

The descriptive statistics of the constructs are presented in Table 2. There was no missing value, and the data was free from any outlier. The skewness values ranged from −2.214 to 0.289 and the kurtosis values ranged from -1.284 to 7.433. Kline (2005) stated that the levels of skewness and kurtosis should fall from 3 to 10 to be considered normal for data. The data is normally distributed for further analysis.

5.2. SEM analysis

The study employed PLS-SEM for model estimation. The authors first analyzed measurements for validity in line with the two-step method suggested by Becker et al. (2012). In the second step, the analysis of the structural equation model was done to test the hypothesized relationships in the research framework.

5.2.1. Measurement model analysis

Once the preliminary analysis is done, the researchers investigated data reliability and validity by employing PLS-SEM. Accordingly, Cronbach alpha (α) and Composite Reliability (CR) were examined to assess the reliability and convergent validity and discriminant validity were observed for validity inspection. The cut-off value for outer loadings should be above 0.6 (Hair, 2009), and the items having less than the cut-off value are suggested to be deleted. Therefore, some items were removed due to a loading of less than 0.5, and to meet the AVE value of higher than 0.5. Thus, one item from IND and two items for ITC, and three items from TBLS were removed.

Table 3 shows the outer loadings, Cronbach alpha (α) and CR; where all the measurement items had achieved the cut-off values above 0.6 for all outer loadings and both the values of Cronbach alpha (α) and CR are above 0.7.

Additionally, the authors inspected the discriminant validity for each of the indicators. According to Fornell and Larcker (1981), once an indicator's AVE is higher than each correlation coefficient with other constructs, then it achieves the discriminant validity and the diagonal numbers (highlighted) of the table indicate the value of the square root of AVE. The results presented in Table 4 meet this requirement and thus establish that recommended discriminant validity has been attained.

Figure 3 presents the measurement model assessment showing the relationship between the variables. Based on the varaibles, the measurement model offers reliability and validity.

5.2.2. Structural model analysis

Further analysis was conducted to test the hypotheses once the reliability and validity were examined. Direct hypotheses testing is shown in Figure 4, and the results are presented in Table 5. The study

Table 1. Constructs/items used in the research questionnaire.

Construct	Items	Sources
Top management commitment		
Goals & objectives	In order to implement Industry 4.0, our top management…	Padma et al. (2008); Ugboro and Obeng (2000)
	sets policy and strategy based on Industry 4.0.	
	communicates Industry 4.0 related initiatives to all employees.	
	assesses Industry 4.0 policy periodically and consequently.	
	emphasizes continuous review and improvement on Industry 4.0.	
Resource allocation	In order to implement Industry 4.0, our top management…	Padma et al. (2008)
	allocates sufficient resources.	
	allocates sufficient resources to train employees.	
	allocates sufficient budgets for Industry 4.0 projects.	
	spends a significant proportion of time in Industry 4.0 planning.	
Supply chain integration		
Customer integration	While implementing Industry 4.0, our organization…	Flynn et al. (2010)
	communicates with our major customers through information networks.	
	establishes quick ordering systems with our major customers.	
	shares our available inventory with our major customers.	
Supplier integration	While implementing Industry 4.0, our organization…	
	exchanges information with our major suppliers through information networks.	
	establishes quick ordering systems with our major suppliers.	
	major suppliers share their production capacity with us.	
Internal integration	While implementing Industry 4.0, our organization…	
	enables data integration among internal functions.	
	employs real-time searching of the inventory level.	
IT infrastructure		
Managerial IT capability	In order to implement Industry 4.0, our organization's IT manager…	Ajamieh et al. (2016); Chanopas et al. (2006)
	understands the policies and goals of the organization towards Industry 4.0.	
	supports Industry 4.0 activities.	
	provides adequate funding.	
	redesigns IT processes to match with the opportunities of Industry 4.0.	
Technical IT capability	In order to implement Industry 4.0, our organization/organization's	
	supports IT personnel in designing excellent databases.	
	supports in developing excellent IT applications.	
	supports in improving the Industry 4.0 project's efficiency.	
	IT personnel know different programming languages.	
Industry 4.0 implementation		
Vertical integration	While implementing Industry 4.0, our organization's technological integration....	Pérez-Lara et al. (2020)
	enhances employees' innovation performance.	
	helps employees to manage the tools and techniques.	
	enables the creation of various products.	
	allows in improving the product quality.	
Horizontal integration	While implementing Industry 4.0, our organization's technological integration....	
	makes the inventory-related information visible throughout the supply chain.	
	helps to maintain a smart product order management system.	
	allows building cloud-based customer service data management.	
	assists for early market entrants.	
TBL sustainability		
Economic sustainability	Implementing Industry 4.0 helps our organization to achieve sustainability by....	Yong et al. (2020)
	decreasing the cost of energy consumption.	
	reducing the cost of purchasing materials.	
	offering better products/services to customers.	Teo and Pian (2003)
	increasing return on financial assets.	Haseeb et al. (2019)
	improving market share.	
Environmental sustainability	Implementing Industry 4.0 helps our organization to achieve sustainability by....	Zhu et al. (2008); Zhu and Sarkis (2004)
	energy saving.	
	reducing the negative impact on air quality.	
	decreasing the consumption of harmful materials.	
Social sustainability	Implementing Industry 4.0 helps our organization to achieve sustainability by....	Yong et al. (2020)
	providing health and safety requirements for the employees.	
	developing new product that reduces health risks for consumers.	

Table 2. Descriptive statistics of the constructs.

Construct	Mean	SD	Kurtosis	Skewness	Cronbach's alpha
Top management commitment	4.1784	0.55850	1.414	-1.184	0.860
Supply chain integration	2.8970	0.97567	-1.284	0.289	0.929
IT infrastructure	4.0936	0.52565	2.932	-1.327	0.813
Implementation of Industry 4.0	4.2751	0.49396	7.083	-2.214	0.838
TBL sustainability	4.2156	0.49073	7.433	-2.178	0.846

Table 3. Results of the measurement model.

Construct	Items	Outer Loadings	AVE	CR	rho_A
Top management commitment	TMC1	0.769	0.505	0.891	0.866
	TMC2	0.775			
	TMC3	0.697			
	TMC4	0.630			
	TMC5	0.739			
	TMC6	0.677			
	TMC7	0.695			
	TMC8	0.695			
Supply chain integration	SCC1	0.816	0.655	0.938	0.911
	SCC2	0.827			
	SCC3	0.828			
	SCC4	0.856			
	SCC5	0.780			
	SCC6	0.817			
	SCC7	0.788			
	SCC8	0.760			
IT infrastructure	ITC1	0.705	0.516	0.864	0.823
	ITC2	0.735			
	ITC3	0.673			
	ITC4	0.780			
	ITC5	0.643			
	ITC6	0.762			
Implementation of Industry 4.0	IND1	0.705	0.507	0.878	0.839
	IND2	0.759			
	IND3	0.687			
	IND4	0.716			
	IND6	0.719			
	IND7	0.711			
	IND8	0.687			
TBL sustainability	TBLS1	0.749	0.519	0.883	0.850
	TBLS2	0.744			
	TBLS4	0.749			
	TBLS6	0.681			
	TBLS7	0.681			
	TBLS8	0.672			
	TBLS10	0.763			

considered a minimum level t-value of 1.96 for accepting or rejecting the hypotheses.

The results illustrate that all the direct relationships except supply chain integration have achieved the t-value above 1.96, indicating a significant relationship. In addition, the relationships have a positive beta value that indicates a direct relationship. The results demonstrate that top management commitment and IT infrastructure have positive relationships with "effective implementation" of Industry 4.0, but supply chain integration cannot meet the expected t-value above 1.96; therefore, the relationship related to supply chain integration is not significant. The relationship between the effective implementation of Industry 4.0 and TBL sustainability is significant. The effect of top management and IT infrastructure on effective implementation of Industry found β-value 0.465, 0.344, and t-value 6.320 and 4.055, respectively; thus, the hypotheses are accepted.

At the same time, the effect of supply chain integration on the "effective implementation" of Industry and TBL sustainability resulted in β-value 0.078, -0.047 and t-value 1.376 and 0.901, which is less than 1.96; therefore these relationships are not significant. Additionally, the effect of top management and IT infrastructure on TBL sustainability showed β-value 0.325,

Table 4. Discriminant validity.

Construct	ITC	IND	SCC	TBLS	TMC
IT Infrastructure (ITC)	**0.718**				
Implementation of Industry 4.0 (IND)	0.645	**0.712**			
Supply Chain Integration (SCO)	0.135	0.163	**0.810**		
TBL Sustainability (TBLS)	0.627	0.721	0.067	**0.721**	
Top Management Commitment (TMC)	0.626	0.687	0.082	0.701	**0.711**

0.178, and t-value 4.020 and 2.685; thus, these hypotheses are accepted. Finally, the relationship between the "effective implementation" of Industry and TBL sustainability showed β-value 0.391 and t-value 4.285.

Table 5 demonstrates the direct effects. The direct effect of top management and IT infrastructure on "effective implementation" of Industry 4.0 and TBL sustainability is significant. The impact of the "effective implementation" of Industry on TBL sustainability is also significant. However, the supply chain integration's direct effect on the effective implementation of Industry and TBL sustainability is not significant.

The mediation effects are depicted in Table 6. The results confirm that both the variables of top management commitment and IT infrastructure and their relationships with TBL sustainability are mediated by the effective implementation of Industry 4.0.

In the study, Figure 3 illustrates the r-square (R2) value of 0.618 for TBL sustainability. Thus, all the constructs tend to bring a 61.8 % change in TBL sustainability which is good (Chin, 1998).

Furthermore, predictive relevance (Q2) indicates the model efficiency and the value should be above zero presented in Table 7.

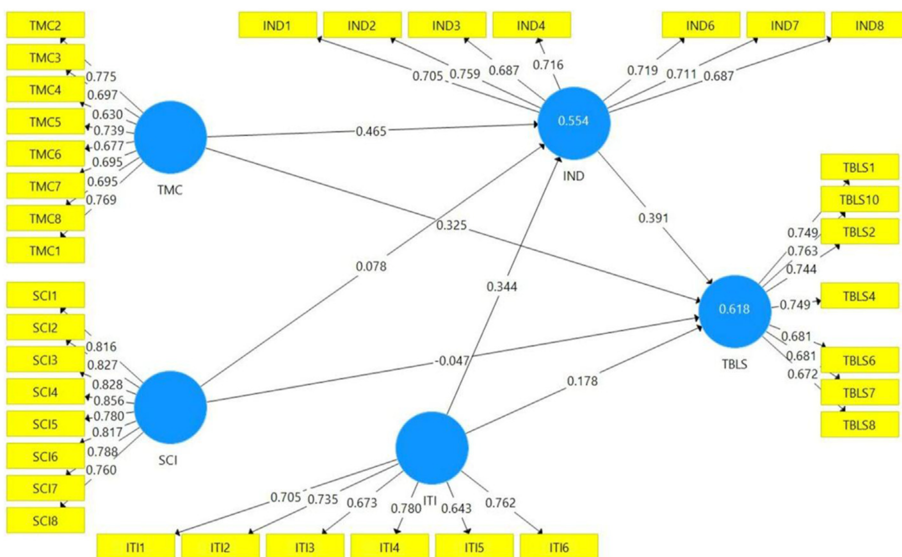

Figure 3. Measurement model assessment.

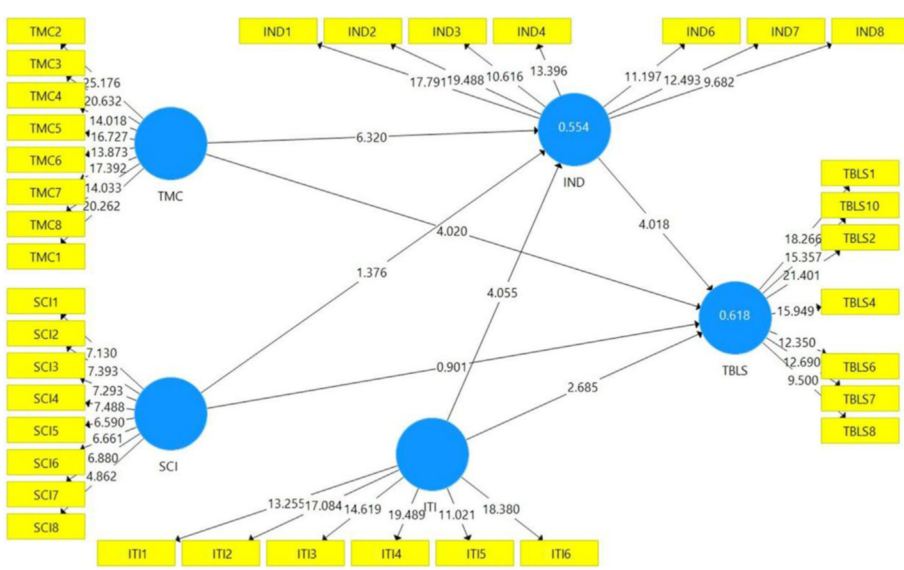

Figure 4. Structural model assessment.

Table 5. Direct relationship.

Hypotheses	(O)	(M)	(STDEV)	T Statistics	P Values	Validation
IT Infrastructure - > Implementation of Industry 4.0	0.344	0.341	0.085	4.055	0.000	Supported
IT Infrastructure - > TBL Sustainability	0.178	0.180	0.066	2.685	0.007	Supported
Implementation of Industry 4.0 - > TBL Sustainability	0.391	0.390	0.097	4.018	0.000	Supported
Supply Chain Integration - > Implementation of Industry 4.0	0.078	0.083	0.057	1.376	0.169	Rejected
Supply Chain Integration - > TBL Sustainability	0.047	0.044	0.052	0.901	0.368	Rejected
Top Management Commitment - > Implementation of Industry 4.0	0.465	0.465	0.074	6.320	0.000	Supported
Top Management Commitment - > TBL Sustainability	0.325	0.322	0.081	4.020	0.000	Supported

6. Discussions

This study aimed to explore the role of determinants in implementing Industry 4.0 to achieve sustainability goals among Malaysian SMEs. To achieve this objective, the authors integrated a framework considering the firm-level characteristics to offer a theoretical framework of the “effective implementation” of Industry 4.0 leading to TBL sustainability. In addition, the study used a field survey of randomly selected SME managers to validate the research framework. In the following paragraphs, the implications of the study findings are discussed.

6.1. Main findings

Concerning the first research question – whether the determinants (top management commitment, supply chain integration, and IT infrastructure) influence the “effective implementation” of Industry 4.0 and TBL sustainability – it can be concluded that the determinants enable them to implement Industry 4.0 successfully to increase revenue and social well-being and decrease environmental pollution leading to achieving TBL sustainability. Regarding the second research question – whether the “effective implementation” of Industry 4.0 contributes to achieving TBL sustainability – the study suggests that the effective implementation of Industry 4.0 enables firms to utilize the capabilities and natural resources in a dynamic way ensuring sustainability. The findings of the study revealed that the determinants such as top management and IT infrastructure have a significant impact on Industry 4.0 implementation and TBL sustainability among SMEs. However, the results validated an insignificant effect of supply chain integration on the Industry 4.0 implementation and TBL sustainability; different from the findings of Younis and Sundarakani (2019).

The first significant variable, top management commitment, involves the strongest positive effect, and the findings indicate that commitment and constructive support are very important in Industry 4.0 implementation. The result is consistent with the research assumption and previous studies. Arnold, Veile, and Voigt (2018) described top management as influential individuals who employ their maneuvering capability to promote technology adoption; Reyes et al. (2016) and Leung et al. (2015) also draw a similar conclusion. According to the aforementioned authors, top management ensures appropriate resource allocation to introduce and implement emerging technologies such as Industry 4.0 to support TBL sustainability. Researchers demonstrated that Industry 4.0 could improve revenue earning and social well-being and reduce environmental pollution (Brettel et al., 2014; Weyer et al., 2015; Zawadzki and Żywicki, 2016), leading to TBL sustainability.

Additionally, the study findings show that IT infrastructure has a significant impact on Industry 4.0 implementation and the TBL sustainability of SMEs. This result is consistent with the study conducted by Lin et al. (2018); where the authors showed that IT infrastructure such as infrastructure, readiness, competence, compatibility, and standard could significantly impact Industry 4.0 implementation. The findings correspond with those by Yeh et al. (2015) that IT infrastructure plays an essential role in Industry 4.0 technology adoption. IT infrastructure enables innovative technologies to communicate among themselves and accelerate the adoption of other smart technologies with various capabilities facilitating automation. Hence, firms need to prioritize the implementation of IT efficiently and strategically to prepare the technological foundation for further adoption of Industry 4.0 related technologies such as Artificial Intelligence (AI), robotics, and so on. This study, therefore, argues that firms must develop IT infrastructure first before adopting the full-fledged Industry 4.0 platform to attain TBL sustainability. Firms should also ensure that these initiatives are completely executed to fulfil their expected targets and enhance organizational efficiency, thereby contributing to building a sustainable society.

At the same time, the study results revealed an insignificant effect of supply chain integration which is in line with the findings of Vanpoucke et al. (2017) and Vereecke and Muylle (2006). They have concluded that there are many un-orchestrated supply chains, as well as coordination failures in supply chain integration. They revealed that focusing on only one dimension of the supply chain may affect supply chain integration. Additionally, Terjesen et al. (2012) have shown that supply chain integration does not significantly contribute to the competitive advantage that can enable organizations to attain sustainability. Wiengarten et al. (2019) supported the same view claiming that supply chain integration does not lead to unambiguous profitability or sustainability. There may be some causes; firstly, this study is based on data from managers of

Table 6. Mediation effect.

Hypotheses	(O)	(M)	(STDEV)	T Statistics	P Values	Validation
IT Infrastructure - > Implementation of Industry 4.0 - > TBL Sustainability	0.134	0.134	0.049	2.734	0.006	Supported
Supply Chain Integration - > Implementation of Industry 4.0 - > TBL Sustainability	0.031	0.032	0.023	1.315	0.189	Rejected
Top Management Commitment - > Implementation of Industry 4.0 - > TBL Sustainability	0.182	0.183	0.058	3.134	0.002	Supported

Table 7. Predictive relevance (Q2).

	SSO	SSE	Q^2 (=1-SSE/SSO)
Implementation of Industry 4.0 (IND)	1393	1024.733	0.264
TBL Sustainability (TBLS)	1393	965.484	0.307

Malaysian SMEs; most of them are independent firms not heavily integrated within the global value chain and have less exposure to the foreign customers, suppliers, and supply chain partners. As the SMEs in the emerging countries are yet to adequately integrate their supply chain within the global value chains, the strength of the relationship between supply chain integration and sustainable performance is still weak due to the lack of complete configuration and learning effect. The SMEs are still in the preliminary phase of learning and implementing the integration practice; therefore, the collaboration with the suppliers and customers is not fully integrated (Wiengarten et al., 2019). Thus, supply chain integration has a lesser influence on Industry 4.0 implementation. Additionally, the SMEs are in the initial stage of IT adoption; limited IT and resources may cause the insignificant effect of supply chain integration (Vanpoucke et al., 2017). Furthermore, supporting the dynamic capability view (DCV), Flynn et al. (2010) revealed that when the level of supply chain integration is relatively low, it will not affect performance, such as Industry 4.0 implementation (Flynn et al., 2010) also claimed that any more developments would bring about better results, even any initiative, when a supply chain has been integrated. Despite the insignificant relationship between the supply chain and the effective implementation of Industry 4.0, it is recommended to develop and integrate smart technologies in the SME's supply chain to integrate the customers, suppliers, and supply chain partners in the value chain. Additionally, the findings show that managers should recognize that certain levels of integration are incompatible with improving the organization's efficiency; instead, it may come at a substantial expense (Wiengarten et al., 2019). Supply chain integration would likely cost more resources initially but have more significant potential for future growth. Therefore, managers should take a particular integration strategy based on the sourcing requirements and circumstances. The performance of supply chain integration depends mainly on the organizational design (Wiengarten et al., 2019). Thus, managers need to recognize the organization's strategic pre-disposition of supply chain integration which may have a strong or negligible effect on sustainable performance.

Regarding the second research question – whether the “effective implementation” of Industry 4.0 contributes to achieving TBL sustainability – the study confirms that Industry 4.0 implementation significantly influences economic, environmental, and social sustainability. The study results affirm that successful implementation of Industry 4.0 contributes to revenue earnings for the firm, increases the utilization of natural and renewable resources, decreases resource consumption, and enhances the social well-being that influences the TBL. This view is supported by Braccini and Margherita (2019) and Müller et al. (2018) who revealed that Industry 4.0 promotes TBL sustainability by improving production efficiency and product quality, ongoing energy consumption tracking, a safe working climate, and reduced workloads and job satisfaction.

Moreover, focusing on the third research question – does the “effective implementation” of Industry 4.0 mediate the relationship between the SMEs’ capabilities and TBL sustainability – the study validates the mediating role of “effective implementation” of Industry 4.0, which serves as the underlying mechanism to explain the relationship between SMEs capabilities and TBL sustainability. The findings reveal that Industry 4.0 implementation should be accomplished through building dynamic capabilities among SMEs. Some review studies have discussed the role of Industry 4.0 implementation in the relationship between the determinants of Industry 4.0 and sustainability (de Sousa Jabbour et al., 2018; Machado et al., 2020; Sony and Naik, 2020). However, from the Industry 4.0 perspective, very few researchers have empirically investigated how the “effective implementation” of Industry 4.0 mediates the relationship between the determinants and TBL sustainability. In this regard, this study empirically tests the relationship suggesting that the mediation effect of Industry 4.0 implementation indicates that the incorporation of proper mediators will help to further clarify the determinants to achieve sustainable development goals.

6.2. Significance of the study

In recent years, Industry 4.0 and its determinants have acted as a very crucial concept for SMEs in achieving TBL sustainability, and hence several kinds of research are conducted across disciplines. However, most of the studies on Industry 4.0 integrated Technology-Organization-Environment (TOE) theory and Diffusion of Innovation (DOI) model (Arnold et al., 2018; Hassan et al., 2017; Lin et al., 2018; Maduku et al., 2016), and very few studies assessed Industry 4.0 determinants from the dynamic capabilities view (Díaz-Chao et al., 2020; Felsberger et al., 2020). As Industry 4.0 involves a dynamic environment, and the resources need to be configured to gain competitive advantage, investigating the determinants from the dynamic capabilities view provides valuable insights into existing knowledge. Accordingly, employing the DCV, this study shows that the determinants act as the foundations and significantly influence Industry 4.0 implementation enabling SMEs to attain competitive advantage and remain sustainable from an economic, environmental, and social perspective.

In the current literature, Industry 4.0 is understood either through its implementation or adoption procedure (Arnold et al., 2018; Masood and Sonntag, 2020; Prause, 2019). As a result, the mediating role of Industry 4.0 remains unclear (de Sousa Jabbour et al., 2018). To fill this research gap, this study investigated the effective implementation of Industry 4.0 as a mediating variable and found that implementing Industry 4.0 enables SMEs to incorporate, build, and transform their existing resources (the determinants) with the employment of horizontal, vertical, and end-to-end integration.

The study also demonstrated that the effective implementation of Industry 4.0 acts as a crunch point for TBL sustainability; Industry 4.0 enables profit maximization through production efficiency, improves the environmental condition by reducing material and energy consumption, and provides a healthy and safe work environment for the employees.

Furthermore, the study model is empirically validated proving its significance toward sustainability. The study results will encourage many academicians to explore more avenues of Industry 4.0 implementation and sustainability. Top management commitment and IT infrastructure have shown very positive results offering significant managerial acumen in achieving the same, especially in Malaysian SMEs. These industries may redesign their strategies to capitalize on the advantages arising from Industry 4.0 implementation in achieving sustainability. As the adoption of Industry 4.0 is still at the stage of infancy in Malaysia, this study results will be very useful for practitioners and academicians to explore other dimensions that can bring success.

6.3. Limitations and future study

The current research offers practitioners useful guidance, although there are some constraints. We need to be cautious in generalizing the findings of this study as the study has been undertaken in the context of SMEs in Malaysia, an emerging country where global value chain integration is still relatively low. Therefore, implementing current research findings in other market settings should be taken with caution. Moreover, the questionnaire-based survey is a further limitation of the study as a qualitative study and can produce better results through conducting multi-level analysis. Another constraint of the study is that it was conducted during the COVID-19 pandemic. Therefore, the supply chain findings contradict the assumption of positive relationship with Industry 4.0 and sustainability; therefore, a future study in a typical business situation with a larger dataset is encouraged.

Further studies employing the current framework on technology-based manufacturing firms may provide better findings as the SMEs cannot fully incorporate Industry 4.0 due to the shortage of investment, particularly in Malaysia. Additionally, the paradigm of Industry 4.0 has newly emerged in literature, and this study considered only three determinants; therefore, future research can focus on other determinants such as skilled human resources, cultural setting, and uncertain conditions to obtain better findings that may influence accomplishment Industry 4.0 implementation.

From a cultural perspective, global implementation approaches of Industry 4.0 and country-wise market settings are different; therefore, describing only the Malaysian context may restrict the generalization of the study. Thus, a benchmarking analysis, including a comparison between the Malaysian context with another comparable emerging market will help to understand better the Industry 4.0 scenario and the adoption and implementation procedure of this paradigm.

7. Conclusion

While the idea of TBL sustainability was devised a few decades ago, there is insufficient research to study the main links between DC and sustainability, especially in the emerging markets context. Considering the research gap, the study contributes to Industry 4.0 research by exploring determinants such as top management and IT infrastructure that facilitate the "effective implementation" of Industry 4.0 with a positive effect on TBL sustainability. To answer the first research question, the study demonstrates that top management commitment and constructive support are very important in Industry 4.0 implementation that translate into achieving the sustainability goals. Furthermore, IT infrastructure enables SMEs to speed up the adoption of smart technologies with various capabilities facilitating Industry 4.0 implementation. Furthermore, the "effective implementation" of Industry 4.0 contributes to minimizing cost, maximizing profit, enhancing eco-friendly practices by reducing resource consumption, lessening emissions and energy-saving, and contributing to the well-being of society that is conducive to answering the second research question. Finally, in answering the third research question, the study findings also demonstrate that the relationship between the determinants and TBL sustainability can be mediated by the "effective implementation" of Industry 4.0. Based on the findings of the study, the industry leaders need to harness the dynamic capabilities of Industry 4.0 to take advantage of and maximize the nation's natural resources. This study assists policy-makers and practitioners in orchestrating the SMEs' dynamic capabilities essential for Industry 4.0 implementation to achieve sustainable development goals.

Declarations

Author contribution statement

Sreenivasan Jayashree: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohammad Nurul Hassan Reza: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Chinnasamy Agamudai Nambi Malarvizhi: Contributed reagents, materials, analysis tools or data; Conceived and designed the experiments.

Muhammad Mohiuddin: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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