The management of Industry 4.0 technologies and environmental assets for optimal performance of industrial firms in Malaysia

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Abstract
The integration of Industry 4.0 (I4.0) has emerged as an innovative paradigm for industrial firms contemplating environmental and economic issues. This study explicates the role of I4.0 technologies (I4.0TEC) in reinforcing the management of environmental assets (ENVASS) as well as optimizing financial performance (FP). The data in this research was collected from 738 industrial firms in Malaysia between 2009 and 2018. The analyses of ordinary least square statistics (OLS) and structural equation modeling (SEM) delineated three major findings. The individual effect of ENVASS, robotization, and flexibility in production technologies has a marginal impact on sales, exports, and labor productivity indicators. The complementarities of these variables represent a similar effect on the performance indicators. The findings related to gross operating margin elucidate that ENVASS and I4.0TEC have neither individual nor complementarity effects. This was explained by developing a robust model by integrating ENVASS, I4.0TEC, spending and investing in R&D, flexibility in production, and human capital management. Our findings have confirmed that the proposed model offers a functional toolkit for the firms considering optimizing their profitability by leveraging ENVASS and I4.0TEC. This research also contributes to developing an ethical business model for the circular economy.

Keywords Industry 4.0 · Environmental assets · Dynamic capabilities · Firms’ performance · Environmental management · Malaysia

Introduction
The German government initiated the concept of Industry 4.0 (I4.0) in 2011 as a high-tech strategic persona to encounter the challenges faced by the manufacturing industry (Birkel and Muller, 2021). Launching I4.0 has simultaneously attracted the attention of information technology (IT) oriented manufacturing systems to create a sustainable society (Khan et al., 2021a). I4.0 has introduced emerging technologies that helped manufacturing firms maximize their output and improve resource utilization (Kamble et al. 2018). This huge economic and sustainability potential of I4.0 has led industrial firms to increase investment to develop and integrate I4.0 to maintain their competitive advantage (Felsberger et al. 2020). I4.0 includes new technologies such as cyber-physical systems (CPSs), the Internet of Things (IoT), autonomous robots, visualization technologies, cloud computing, big data analytics, additive manufacturing, and digital twins (Lio et al. 2017; Tao et al. 2019). These technologies have opened the pathways for industrial development by improving production and efficiency in modern industrial firms. The growth of I4.0 and its exceptional fitness to a broad discussion on industrial sustainability has accelerated its implementation and inclusion in academic and managerial policy debates (Kiel et al., 2017; Milano et al., 2017; De Sousa Jabbour et al., 2018a). The literature has attempted to link I4.0 and sustainability with pros and cons. The findings of past studies elucidate that it supports optimizing the processes and positively contributes to environmental sustainability performance (Herrmann et al. 2014; Kiel et al. 2017) as it improves resource utilization and reduces waste (Beier et al. 2020; Stock et al. 2018). Whereas, some studies claim that the escalating usage of I4.0 may result in large
production of industrial waste and higher demand for energy resources (Beltrami et al. 2021; Ford and Despeisse, 2016).

Innovative technologies play a critical role in the nexus between environmental actions and firms’ performance (FP). The earlier studies have confirmed that promulgation of environmental regulations and proactive attitude drive firms toward operational transformation through the adoption of technology and development of innovation (Elkington 1994; Shrivastava 1995; Ramanathan et al. 2017). Firms improve their economic and environmental sustainability performance and achieve a win–win situation by coordinating their environmental initiatives and using innovative technologies (Porter and van der Linde 1995; Rexheuser and Rammer 2014; Adams et al. 2016; Chupradit et al. 2021). Progressive organizations leverage technologies and innovations to maximize operational efficiency by accessing renewable sources and energy, minimizing waste, and circulating the materials through recycling and reuse (Chen et al. 2020). These factors are essential and have become a major contributor to authenticate firms’ environmental management actions and improve performance (Cheng and Shiu 2012; Ozus-aglam et al. 2018b). Besides technologies and innovations, the plethora of literature indicates that firms can develop a range of capabilities for better preparation for sustainability and resolve economic, social, and environmental problems (Ervin et al. 2013; Liu et al. 2020; Wang et al. 2020). Firms’ access to information and resources help in developing environmental response strategy, redesigning organizational flexibility, enhancing research and development (R&D) initiatives, and expertise in technical and innovative capabilities to get a step closer to effective management of human capital and their sustainable agenda (Amjad et al. 2021; Girod and Whittington 2017; Arda et al. 2019; Singh et al. 2020).

Even though I4.0 has been recognized as a key driver of sustainability (Beier et al. 2017), the extant literature provides nascent evidence about the implementation of I4.0 to assess the sustainability of industrial firms, which signals a crossover between I4.0 and sustainability (Jabbour et al., 2020; Kiron and Unruh, 2018; Fisher et al., 2018; Sharma et al. 2020). The scant literature has used I4.0 and related technologies to explore concepts of triple bottom line approaches and circular economy (Asimwe and de Kock, 2019; Jabbour et al. 2020; Nobre and Tavares, 2017; Ribeiro et al. 2020; Alcayaga et al. 2019; Rosa et al. 2020; Odwazny et al. 2018). In comparison, the findings of earlier studies have highlighted the role of I4.0 in creating value for industrial firms to develop sustainable business models (Machado et al., 2020; Strandhagen et al., 2017; Tirabeni et al., 2019), which establishes the significance of infrastructure in the form of dynamic capabilities essential for the diffusion of I4.0.

This research aims to bridge this gap by investigating the nexus between firms’ technology and innovation adoption to render environmental actions and their cumulative impact on the FP of firms. Precisely, it explores the effects of Industry 4.0 technologies (I4.0TEC) on environmental asset management to optimize FP. I4.0 is contextualized as an innovative ecosystem of industrial firms guided by the implementation of the latest digital technology (Lu, 2017; Xu et al., 2018) with an ability to transform production systems and organizations’ operational and strategic decision-making (Piccarozzi et al. 2018; Szalavetz 2019; Benítez et al. 2020). The findings of earlier studies have confirmed that I4.0TEC has the capabilities to improve firms’ productivity; however, consolidated firms are yet to leverage these innovative methods to boost their economic and environmental performance (Gillani et al. 2020; Khan et al. 2021b; Olah et al. 2020; Brozzi et al. 2020). I4.0TEC is categorized as the driver of environmental assets and FP (Sharma et al. 2020; De Sousa-Jabbour et al. 2018a). Due to its economic and environmental performance and reputation as a potential driver of firms’ performance (Kamble et al. 2018; Beier et al. 2020), it has become a popular research agenda of empirical and theoretical business case studies (Bag et al. 2021; Bai et al. 2020; Lamperti et al. 2020; Li et al. 2020; Ordieres-Mere et al. 2020).

Accordingly, this study documents fresh empirical evidence by theoretically testing the impact of I4.0TEC on environmental assets (ENVASS), which will help explain FP and be expected to make several discrete contributions to the literature. First, it empirically authenticates the theory of dynamic capability view (DCV) by implementing it to develop the conceptual framework (Teece et al. 1997; Teece 2014, 2016). The components of DCV are deployed as organizational resources such as knowledge, assets, organizational architecture, and strategic direction to achieve competitive advantage and constitute unique capabilities (Teece 2007; Amui et al. 2017). Second, it expands the existing literature related to I4.0TEC by offering a solution to two important research questions: What is the influence of I4.0TEC and ENVASS on the performance of firms? Is there any robust business model and approach to determine optimal performance of firms by leveraging on dynamic capabilities of I4.0TEC and ENVASS? Lastly, it is expected to contribute to offering a toolkit for the policymakers and regulators of industrial firms concerned with the implications of I4.0TEC and ENVASS to achieve the financial goals.

The above-highlighted questions are answered by surveying 738 industrial firms in Malaysia by collecting data between 2009 and 2018. Malaysia is touted as one of the developing countries in Southeast Asia and a pioneer of industrialization in the region through its economic growth (Rasiah and Krishnan 2020). Industrialization has played a major role in expanding economic growth and facilitating the achievement of missions (Wawasan 2020; Chin et al. 2019). However, in the process of industrialization
and economic expansion, the industrial firms have heavily polluted the environment (Awang et al. 2000); such as industries in Klang Valley, Penang, and Iskandar contribute to one-third of the overall pollution of the country (Azmi et al. 2010). To tackle these issues, the government of Malaysia has imposed stringent environmental regulations on industrial firms. Nonetheless, the effectiveness and the interaction of these regulations with the performance of firms need further investigation. The earlier discussion indicates that I4.0TEC and ENVASS have varying effects on FP. However, the business model proposed and tested in this research is expected to be robust as it combines I4.0TEC, ENVASS, R&D, flexible production and organization system, and human capital management assets, which will help in explaining industrial firms’ sales, exports, labor productivity, and gross operating margins.

The rest of the study proceeds as follows: Underpinning concepts, theoretical framework, and hypotheses are discussed in the “2” section. The details of the methodological approach and research strategies are explained in the “6” section. The “10” section highlights major findings, and the relevance, authentication, and implications of these findings are further elaborated in the “14” section.

**Empirical literature**

**Impact of I4.0TEC and environmental actions on firms’ performance**

The dynamic construct of I4.0 is viewed as a multidimensional concept and refers to the existing processes which involve digital transformations and structural changes in industrial firms (Szalavetz 2019; Piccarozzi et al. 2018). Collectively, it indicates the evolution of flexible and additive production systems (Weller et al. 2015; Brettel et al. 2014), integrated traditional physical and digital instruments (or cyber-physical systems) (Monostori et al., 2016), usage of new digital technology (for example Internet of Things (IoT), internet facilities, cloud computing, wireless sensor networks, big data, robotics, and artificial intelligence) (Wang et al. 2016; Gillani et al. 2020), organizations’ innovative methods related to operation including structural changes in the human labor within production system (or smart working and smart production (Phuluwa and Mpofu 2018; Longo et al. 2017), and data-driven strategic decision-making (Porter and Heppelmann 2015; Brynjolfsson and McElheran 2016). The seminal studies on the impact of I4.0TEC, digital automation/robotics (Ballestar et al. 2020; Autor and Salomons 2018), big data, and data-driven decision-making (Müller et al. 2018b; Brynjolfsson and McElheran 2019; Wu et al. 2020a) have empirically confirmed that these technologies create an innovative ecosystem within firms which modifies production and work processes and it ultimately improves firms’ productivity (Gillani et al. 2020; Camina et al. 2020). The findings of recent studies have concluded that firms’ structural changes facilitate reducing pollution and emission of harmful waste and energy saving during production (García de Soto et al. 2018; Díaz-Chao et al. 2021). The consolidation of I4.0TEC as efficient and innovative sources (referred to as EITI) has activated structural changes in firms’ production driven by the adoption of innovative production methods, which positively affect production efficiency. These technologies minimize energy usage during production, preventing unwanted waste contamination and improving overall efficiency (Cheng and Shiu 2012; Rexhauser and Rammer 2014; Ghisetti and Rennings 2014). Some of the examples of EITI include the usage and/or the adoption of renewable energy technologies (Ozusaglam et al. 2018b; Bechtsis et al. 2018). Despite the emergence and evidence of seminal studies, the nexus between I4.0TEC and ENVASS and their impact on industrial firms’ performance have received less attention in the literature. A few studies have attempted to bridge this research gap by exploring the effects of I4.0TEC and environmental sustainability on industrial firms (ElMaraghy et al. 2012; De Sousa-Jabbour et al. 2018a; Beier et al. 2020; Díaz-Chao et al. 2021). However, the findings of these studies cannot be generalized in the context of the settings of this study due to the existence of other underlying issues in the adoption of I4.0TEC.

The adoption and implementation of I4.0TEC in industrial firms are constrained due to certain drivers and barriers. Muller et al. (2018a) have confirmed that firms’ sustainability, strategic, and operational needs are the major predictors of I4.0TEC. Whereas factors such as the balance between firms and their production needs, employees’ skills and knowledge, and acceptance of I4.0TEC are the major barriers. Similarly, another study has highlighted that the adoption of I4.0TEC in SMEs and their business models can be improved by integrating the virtual and physical world to enhance open innovation and service design models (Prause 2015; Akbar et al. 2021).

Nonetheless, the research on the relationship between I4.0TEC and environmental management and its impact on the firms is still in its infancy. The findings of a recent study indicate that composite indicators of sustainability and cost reduction were positively associated with I4.0TEC (Dalenogare et al. 2018). From an implementation perspective, I4.0TEC yielded positive economic benefits for the firms despite the presence of a weak relationship between environmental sustainability (Brozzi et al. 2020).

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1 The details of environmental and industrial regulations are available on the official portal of the Department of Environment: https://www.doe.gov.my/portalV1/en/tentang-jas/perundangan/akta-kaedah-peraturan-aranah/2/peraturan.
Further evidence from studies in the industrial sector suggested that I4.0TEC has exerted a significant impact on sustainability, guided by the adoption of mobile technologies. Even though I4.0 technologies and environmental management were found to have a positive linkage, researchers have suggested analyzing the performance of each technology. For instance, Bag et al. (2021) evaluated the performance of sustainable resources during the implementation of I4.0TEC and found that 10 advanced dynamic capabilities, namely refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover, mediated the relationship between I4.0TEC and performance of sustainable resources. Similarly, digital platforms in supply chain firms were found as mediators of the usage of digital technologies and economic and environmental performance (Li et al. 2020). From these arguments, it is advanced that higher environmental dynamism increases the mediating effect of other indicators. While analyzing the productivity and economic performance of firms, Ordieres-Mere et al. (2020) found that environmental management actions and I4.0TEC are interrelated. The effectiveness of I4.0TEC relies on several factors, which were categorized as managers’ initiatives to redesign the organizational firms, technical skills, and knowledge acquisition (Yunus 2021).

Empirical studies in the industrial sector have concluded that modern-day firms are yet to leverage the benefits of I4.0TEC to achieve sustainability and the creation of value (Birkel and Müller, 2021; Diaz-Chao et al. 2021; Felsberger et al. 2020). This motivated us to undertake the current research to document empirical evidence of the contribution of I4.0TEC to achieve the United Nations’ agenda of sustainable development goals and explore the methods to instigate improvements in the firms’ social and environmental sustainability, which will eventually optimize firms’ efficiency and productivity (Sharma et al. 2020; Beier et al. 2020).

Theory of dynamic capabilities view

Lately, firms have started to explore strategic resources, acquisition of dynamic capabilities, and management due to escalating uncertainties and increased competitive pressure (Diaz-Chao et al. 2021; Felsberger et al. 2021). This has resulted in a clear distinction between ordinary capabilities related to routine operations and dynamic capabilities. The capabilities mentioned earlier are viewed as high-level capabilities as these help in detecting (faced with uncertain future) developing competitive advantage (through the acquisition of key resources) and transforming firms’ operational structure (shifting or pivot) (Eisenhardt and Martin 2000; Teece 2014). These dynamic capabilities are explained as advanced capabilities in the theory of dynamic capabilities view (DCV) as it helps in creating, reconfiguring, and leveraging key organizational resources and capabilities (Diaz-Chao et al. 2021; Felsberger et al. 2021). Hence, dynamic capabilities are described as “firms’ capabilities of integrating, building, and reconfiguring internal and external sources to address frequently changing environment.” DCV reflects firms’ capabilities to create novel and innovative protocols of competitive advantage guided by the current market positions (Teece et al. 1997). Certain instruments play a key role while firms develop dynamic capabilities to achieve competitive advantage. These elements are an active and supportive organizational learning environment, top management support for experimentation, and effectiveness in recombining resources and transforming existing production methods to develop or launch a new product (Teece 2016). These processes further involve certain knowledge, skill, processes, procedures, organizational structure, and decision-making protocols engaged in detecting opportunities and exploiting and reconfiguring capabilities (Teece 2007).

Firms have used the DCV theory in the past to categorize and explain the strategic factors involved in the competitive advantage, which indicates its evolution from the theory of resource-based view (RBV) (Kraaijenbrink et al. 2010). This evolutionary theory differentiates firms based on the key resources such as the dominance of unique ownership and management and acquisition of rare and inimitable resources (known as VRIN), which are integrated in a way that offers sustainable competitive advantage against competing firms (Eisenhardt and Martin 2000; Barney 1991). DCV theory is the extension of RBV from two aspects: the evolution of capabilities from resources and the transition of static market views to dynamic views in an uncertain market.

RBV was extensively used as a theoretical model in environmental studies as the studies on environmental research considered it to explain the natural-resource-based view (NRBV) of the firms (Hart 1995). In the context of the adoption of environmental management practices, RBV suggests that implementation of environmental management tactics, capabilities, and their integration with environmental technologies may create unique resources for the firms, which will offer a competitive advantage as well as serve environmental and economic goals (Barney 2001; Ozusaglam et al. 2018b; Hart and Dowell 2011). The emergence of technology, innovation, and its thriving role, as explained in Porter’s hypothesis, has diverged the nexus between environmental management and FP to a dynamic approach (Wu et al. 2012; Amui et al. 2017). Studies in the past have confirmed that firms having flexible environmental regulations, highly responsible, and dynamic environmental approaches may enhance their environmental and economic performance by mobilizing dynamic capabilities which involve redesigning, reorganizing, and innovating new production methods (Ramathan et al. 2017; Jiang et al. 2018; Girod and Whittington 2017). The proceeding discussion offers a significant basis
to adopt DCV theory to construct the theoretical framework to analyze the relationship between technologies, precisely digital technologies, and environmental management practices and their effect on FP (Pohl et al. 2019).

**Hypothesis development**

The past studies have claimed that the integration of ENVASS with other assets articulate cost-saving, increasing sale and labor productivity, and improving return over financial assets (Su et al. 2015; Ghisetti and Rennings 2014). Firms use ENVASS and resources for mobilization and development of environmental dynamism actions. Herein, ENVASS refers to the set of financial and non-financial resources deployed to address issues faced by environmental management systems which involve investments in technology and innovation initiatives to gain economic benefits and minimize environmental impacts through the adoption of environmental regulations and implementation of environmental standards ((Diaz-Chao et al. 2021; Felsberger et al. 2020; Ferron-Vílchez and Darnall 2016; Ramanathan et al. 2017; Ozusaglam et al. 2018a)). However, the estimation and measurement of ENVASS and its economic benefits involve broad and complex procedures.

Environmental researchers have started to consider various methods, procedures, and techniques due to the varying nature of public goods and market value factors. These methodologies include contingent analysis, willingness-to-pay research, or multicharacter selection of experiments that focus on environmental priorities and their impacts (Shah 2018; Save 2017). The studies on dynamic perspectives of environmental management systems have predicted several estimation methods and scales for capturing the use of environmental resources, which are alternatively engaged to evaluate results commonly estimated by considering firms’ FP and/or perception of sustainability (Bag et al. 2021; Li et al. 2020; Arda et al. 2019).

The literature on supply chain management has used cost savings to establish a linkage between ENVASS and efficiency (Fang and Zhang, 2018; Bastas and Liyanage, 2018; Koberg and Longoni, 2019). Often, environmental assets proliferate in value chains which escalate the elimination of harmful and toxic materials, lower energy saving, increase consumption, and reduce environmental impact (Ferron-Vílchez and Darnall, 2016; Doran and Ryan, 2016). Various studies have confirmed that firms may become efficient and improve their return on sales (Lo et al. 2012; Rexheuser and Rammer 2014; Ozusaglam et al. 2018b) that will drive firms to minimize the cost of production and improve their brand image (Gonzalez-Benito and Gonzalez-Benito 2008; Ambec and Lanoie 2008; Delmas and Pekovic 2013).

Alternatively, the onset of technologies and innovations has further consolidated the positive relationship between ENVASS and firms’ FP (Shrivastava 1995; Ramanathan et al. 2017). Firms regulated through environmental protection laws have the option to develop a passive or active approach. Studies by Adams et al. (2016) and Porter and Van der Linde (1995) highlighted that firms that develop an active approach/attitude toward environmental regulations focus on adopting technologies and innovations for the transformation of operational activities are able to create a win–win situation. This was further confirmed by Ozusaglam et al. (2018b) and Rexheuser and Rammer (2014) studies that used technologies and innovations to increase firms’ efficiency. Furthermore, effective environmental management leads to exploring different financing sources, which also help in improving firms’ economic performance (Yan and Zhang, 2021). These positive changes in efficiency are associated with environmental sustainability (guided by the usage of technologies of renewable energy or adoption of energy-efficient technologies) or cumulative sustainability of firms (enabled by adopting technology use to achieve better employee output and improve the overall economic situation) (Dangelico and Pujari 2010).

Modern technologies such as I4.0 are labeled as a new era of digital transformation for industrial firms (Lu 2017; Xu et al. 2018; Szalavetz 2019). These technologies create a new innovative ecosystem for the firms to transform their production system, operations, and strategic decision-making (Benítez et al. 2020). The findings of past studies have established that I4.0-driven firms highly rely on flexible and additive production, integration of physical and digital systems, usage of technology (involve second digital wave), development of smart production system, creation of intelligent work organization, and data-driven (big data analytics) decision-making (Brettel et al. 2014; Wang et al. 2016; Longo et al. 2017). Firms with an active attitude toward I4.0 must develop critical capabilities to generate massive financial gains. Particularly, I4.0TEC involves data-driven management (Wu et al. 2020a; Brynjolfsson and McElheran 2019), and industrial automation/robotics (Ballestar et al. 2020; Autor and Salomons 2018) were found to incur positive changes in firms’ productivity (Brozzi et al. 2020; Dalenogare et al. 2018; Camiña et al. 2020). Hence, it is predicted that.

\[ H1. \text{ENVASS and I4.0TEC have a positive impact on the economic performance of firms.} \]

Besides its impacts on economic sustainability, I4.0TEC has huge potential to interact positively and influence environmental sustainability (Birkel and Muller, 2021; Khan et al. 2021a; Sharma et al. 2020). Despite these claims, the evidence related to the impact of I4.0TEC and environmental actions as the drivers of firms’ FP remains at rudimentary phase (De Sousa-Jabbour et al. 2018a) as the usage
of environmental actions were restricted as the residual or experimental drivers (Khan et al. 2021a; Lamperti et al. 2020; Dalenogare et al. 2018). Firms accumulate dynamic capabilities by leveraging on the effective management of ENVASS as it helps generate routines, technical skills, and redesign procedures that eventually facilitate the adoption of environmental technologies. Consequently, an active approach toward environmental regulations improves firms’ adoption of environmental management systems, increases internal efficiency, and lowers the adoption cost of technologies (Birkel and Muller, 2021; Lopez-Gamero and Molina-Azorín 2016; Lopez-Gamero et al. 2008, 2009). Hence, firms considering transform environmental and economic sustainability may deploy the combination of environmental technologies and assets, which will also establish a benchmark for the firms with a passive sustainability approach (Felsberger et al. 2021; Nath and Ramanathan 2016). It is predicted that I4.0TEC may drive the economic and environmental sustainability goals of industrial firms. This argument leads to propose hypothesis 2, which is as follows:

**H2. Collective implementation of ENVASS and I4.0TEC has a higher impact on the economic performance of firms as compared to the isolated implementation.**

Even though firms effectively mobilize their assets to improve economic performance, the empirical findings suggest that some technologies and innovations, particularly related to environmental wastes reduction, fail to save cost and improve efficiency (Diaz Chao et al. 2021; Felsberger et al. 2021; Horvathova 2012; Ozusaglam et al. 2018a; Rexheuser and Rammer 2014). A logical explanation is firms’ failure to fully prepare and acquire knowledge and resources, a mismatch between environmental actions and organizational strategy (Ervin et al. 2013). Studies have categorized several dynamic capabilities, namely the existence of relative environmental strategies and responsibilities to actively mobilize resources (Ali et al. 2021a; Arda et al. 2019; Yang et al. 2015; Lee et al. 2016), moving toward flexibility and reorganization (Russo and Harrison 2005; Girod and Whittington 2017; Abeelen et al. 2013), experienced R&D (Mithani 2017; Lee and Min 2015), technical and innovative knowledge and skill (Ali et al. 2021b; Cainelli et al. 2015; Bhupendra and Sangle 2015; Arvanitis and Ley 2013), and reshaping human capital management to achieve economic, social, and environmental sustainability goals (Aravind 2012; Qureshi et al. 2021; Singh et al. 2020; Yunus, 2021).

Some recent studies have attempted to showcase the impacts of environmental actions and I4.0TEC on firms’ FP (Li et al. 2020; Bai et al. 2020; Bag et al. 2021; Diaz-Chao et al. 2021; Felsberger et al. 2020); it is predicted that different technologies may react differently (Dangelico and Pujaro 2010; Gerstlberger et al. 2016; Fu et al. 2018). This leads us to propose 10 partial hypotheses within the 3rd working hypothesis (Fig. 1).

**H3. The combination of ENVASS, I4.0TEC, R&D, production flexibility, and human capital management has a positive impact on the economic performance of firms.**

### Data and methods

#### Sampling and data collection

To answer the research questions and test the hypotheses, the present study considers two comprehensive surveys of the industrial firms in Malaysia executed by the Department of Statistics Malaysia (DOSM). DOSM web portal also contains reports of the reliable economic, strategic decisions, value elements, and FP statistics of Malaysia’s industrial and small and medium enterprises (SMEs). Our study uses two different survey reports; small and medium enterprises performance (2019) and annual economic statistics of manufacturing sector (2019) published by DOSM.

![Fig. 1 Model and explanatory indicators of industrial firms' performance](image)
These two surveys contain a panel of 3000 industrial firms covering the data between 2008 and 2018. However, this study uses panel data of 738 industrial firms as the selected firms were found to have the desired industrial, economic, financial, and other indicators’ information. These two survey reports are reliable data sources as the presented data complies with scientific and research requirements. Further explanation to use these surveys as the data sources is the detailed segmentation information of different industries such as industry type (manufacturing, energy, and mining) and size (large firms with more than 500 workers and small firms with less than 250 workers and SMEs between 20 and 150 workers). The selection of industries based on their size was due to the difference in the perception of firms in the adoption of environmental management systems (Shabbir et al. 2020). Since these survey reports contain the information of all large firms and also debugged and added new firms in the live panel data which confirms the randomness and reliability criteria of the data. Using official survey reports as data sources is a reliable method as the survey reports are prepared by the industry professionals and authenticated by the relative authorities before publication.

DOSM portal also contains environmental sustainability information which covers the period between 2008 and 2020. The information on environmental sustainability is used to determine environmental performance. Even though time duration was the major constraint to obtaining inclusive information, the researchers have authenticated this research for two reasons. First, it analyzes the relationship between ENVASS, I4.0TEC, and its economic impact on the industrial firms in Malaysia. Based on the theoretical settings of this study, the literature does not contain any evidence which authenticates the contribution of this study. Second, the analysis covers the period between 2009 and 2018, which addresses the time duration requirements in scientific research.

**Variables and estimations**

The performance of industrial firms is the dependent variable in this research, measured by sales, exports, labor productivity, and operating margin. These variables are alternatively measured by real sales’ (SAL) log, which includes merchandise sales, products’ processing, and services’ provision, excluding rappels, the log of real exports (EXP), which include values of sales in the international market, the log of real hourly labor productivity (HLP) which include wage per hour and the log of gross operating margin (GOM) which include the percentage of sales + changes in inventory + other management income excluding purchase, external services, and personal expenses divided by total current income.

ENVASS is an independent variable, and it is measured using different indicators such as expenditure on environmental assets (EAE). It is measured in dichotomous values; if the firms have spent to take environmental action (0 is no and 1 is yes). The investment in environmental assets (IEA) is also an indicator of firms’ expenditure to take an environmental action (0 is no and 1 is yes). Both indicators measure whether the firms have spent on environmental initiatives such as investment in green or renewable technologies, implementation of environmental regulations, and the management of environmental quality standards. The integration of these two indicators generated two input variables: EAEI and ENVASS. The variable EAEI is generated by adding the previous two variables (EAE and EAI), and it is indicated by three values (0, absence of spending or investing in the environment; 1, firms have spent or invested in ENVASS; and 2, firms have spent and invested in ENVASS). The ENVASS is generated by dichotomizing EAEI, and it is indicated by 2 values (0, firms have neither spent nor invested in ENVASS, and 1, firms have mobilized their financial resources to invest in ENVASS. Although the usage of dichotomous variables has obvious restrictions, however, the information disclosed by the firms regarding the mobilization of ENVASS leads to propose an important contribution. This scale directly measures the impact on the firms’ FP when ENVASS has not mobilized and the scenarios when firms have activated their resources to increase performance.

Whereas, I4.0TEC is also an independent variable and it is measured using four dichotomous indicators, namely robotization (R) (determines the usage of industrial robots), computer-aided design and manufacturing (CADM) (measures the usage of CAD or CAM technology), data-driven control (CDC) (determines the use of machines, tools or algorithms to numerically control operational activities), and flexible production technologies (FPT) (determines the usage of non-standardized and high-frequency production technologies). The existence and use of these indicators are represented as 1, and their absence is indicated as 0. Even though the researchers did not have sufficient information pertaining to I4.0TEC, such as Internet of Things (IoT) and additive manufacturing, these technologies were deployed by the past studies to examine the FP of industrial firms (Dalenogare et al. 2018; Liao et al. 2017; Frank et al. 2019). Through the combination of these indicators, we developed an indicator and named it as I4.0 technologies (I4TEC) which contains five values (0 to 4), and estimates the extent

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2 The enactment of environmental quality under Industrial Effluent in Malaysia is covered under Environmental Quality (Industrial Effluent) Regulations 2009, available at https://www.doe.gov.my/portalv1/wp-content/uploads/2015/01/Environmental_Quality_Industrial_Effluent_Regulations_2009_(P.U.A_434-2009).pdf
of its usage (0 indicates no use, 1 indicates one use, 2 indicates 2 uses, 3 indicates three uses, and 4 indicates four uses) in the industrial firms.

We have also created additional variables to analyze the impacts of the complementarity relationship between ENVASS and I4.0TEC. Firstly, each of the I4.0TEC variables (R, CADM, CDC, and FPT) were multiplied with the dichotomous variable of ENVASS, and the resulting variable determines the cumulative use of I4.0TEC and ENVASS (1 indicates cumulative usage; 0 otherwise). Secondly, we also created composite indicators which multiply ENVASS and the usage of I4.0TEC. This step will help in analyzing the level of collective use of I4.0TEC and ENVASS management (0 indicates no usage of technology and ENVASS management; 1 indicates one usage of technology and ENVASS management; 2 indicates two usages of technology and ENVASS management; 3 indicates three usages of technology and ENVASS management; 4 indicates four usages of technology and ENVASS management.

The other variables used in this research include human capital management, indicated as labor cost per worker (LABCOSTW) and measured by the log of real labor cost (gross wage and salary + indemnification + social contribution of firm + contribution to supplementary pension system + other social expenditure) per worker. The expenditure on R&D is measured by the log of real expenditure in research and development (R&D) by the firms. Lastly, a composite indicator is used to measure production flexibility (PRODFLEX) which contains 4 values (0 to 4). These values are obtained by multiplying two input variables known as standardization of products (0 is high; 1 is low) and frequency of changes in a product (0, no changes; 1, product changes less than a year; 2, product changes once a year; 3, product changes more than once in a year; 4, irregular changes). The nominal values of all these variables and indicators were initially deflated; therefore, we used the Paasche index to retrieve the real data. Paasche index measures the cost and energy acquired by the firms to manufacture consumer goods and services. The variables and their indicative measurements are represented in Table 1.

### Data analysis procedures

The impact of ENVASS and I4.0TEC on FP of industrial firms in Malaysia is analyzed using time series data between 2009 and 2018. This research uses arithmetic and econometric techniques to analyze the available panel data and test the hypotheses. Firstly, arithmetic means of the variables were obtained, followed by the

| Table 1 Variables’ indications and measurements |
|------------------------------------------------|
| Variables | Dependent/independent/others | Indicators | Measurements |
| Firms’ performance | Dependent | Sales, exports, labor productivity, operating margin | Log real sales (SAL), log real exports (EXP), log labor productivity/hour (HLP), log gross operating margin (GOM) |
| Environmental assets | Independent | Expenditure in environmental assets (EAE), investment in environmental assets (EAI) | 0, no; 1, yes; 0, no; 1, yes |
| EAEI | Independent | EAI+EAI | 0, no spending or investment; 1, firms have spent or invested; 2, firms have spent and invested |
| ENVASS | Independent | EAE+EAI | 0, firms have neither spent nor invested; 1, firms have invested |
| I4.0 technologies | Independent | Robotization (R), computer-aided design and manufacturing (CADM), data-driven control (CDC), flexible production technologies (FPT) | 1, technologies exist; 0, technologies do not exist |
| I4TEC | Independent | R + CADM + CDC + FPT | 0, no usage; 1, one usage; 2, two usages; 3, three usages; 4, four usages |
| Human capital management | Associated | Labor cost per worker (LCW) | Log real labor cost |
| Research and development (R&D) | Associated | Expenditure on R&D | Log real expenditure in R&D |
| Production flexibility (PRODFLEX) | Associated | Products’ standardization | 0, high; 1, low; 0, no change; 1, product changes less than a year; 2, product changes once a year; 3, product changes more than once in a year; 4, irregular changes |
The industrial firms in Malaysia were characterized based on the management (spending and investing) of ENVASS using ANOVA and crosstab analysis. Then, the marginal effects of the developed hypotheses were tested using the ordinary least squares (OLS) technique. To study the direct, indirect, and cumulative effect of the general combining hypotheses (hypothesis 3) on the firms, the structural equation modeling (SEM) technique was used. Overall, both OLS and SEM techniques analyzed 16 models (12 OLS and 4 SEM) for the panel data of 738 industrial firms. These techniques have been widely used in the literature to explore the relationship between I4.0TEC, ENVASS, and FP of industrial firms due to their accuracy and reliability in measuring the relationship between latent variables (Chao Diaz et al. 2021; Dey et al. 2020; Gupta and Gupta 2020; Hussey and Eagan, 2007; Koh et al. 2020; Park et al. 2014).

### Empirical results

#### A generic overview of ENVASS management, I4.0TEC, and firms’ FP

The descriptive statistics of industrial firms in Malaysia are detailed in Table 2, which are based on the management of ENVASS and describe the value process in these firms. The statistics clearly represent an improvement in the mobilization of ENVASS by the firms between 2009 and 2018. It is also notable that improvement in FP is an indication of extensive ENVASS management (expenditure and investments) in the firms. This result established that the firms that invested and spent in ENVASS generated sales and exports and doubled their values compared to those focused only on investing or spending in ENVASS. However, there is a high difference in firms’ values that fail to mobilize any ENVASS. Similarly, firms with extensive management of ENVASS appear to have a better value-generating process guided by lavish human capital and R&D expenditure as well as a better tendency toward innovation and digitization.

Regarding productivity, environment-intensive firms represent better efficiency as these have rendered rigorous efforts in investing and spending on rewarding and training their labor compared to the firms that failed in mobilizing their ENVASS. Overall, environmental firms are substantially efficient as compared to less or non-environmental firms. Therefore, firms that mobilize their ENVASS enjoy higher gross operating margins, which are also confirmed from the profitability of environmental firms during the year 2009, marking the onset of global economic crises.

#### Estimating individual and complementarity effect on FP of firms

The individual and complementarity effect of ENVASS and I4.0TEC on industrial firms in Malaysia is determined by obtaining the marginal effects using multivariate regression analysis by OLS. This method is compatible with the recent studies in the literature (Autor and Salomons 2018; Ozusaglam et al. 2018b; Dalenogare et al. 2018; Díaz-Chao et al. 2021). The results of individual and complementarity variables on industrial firms’ SAL, EXP, HLP, and GOM are reported in Table 3.

The individual effect of ENVASS and I4.0TEC on the performance indicators is analyzed in model 1. Whereas, model 2 elucidates the complementarity effect of I4.0TEC (usage of robots (R), computer-aided manufacturing (CAM), data-driven control (DDC), and flexible production technologies (FPT)) multiplied by the dichotomous mobilization of ENVASS on the performance indicators. Lastly, the joint effect of I4.0TEC and ENVASS on performance indicators is presented in model 3. All three models have individually analyzed the impact of physical capital (capital per worker) and human capital (labor cost per worker).

Before presenting the models’ fitness of good, it is essential to justify the data normality which is tested by normality, linearity, and homoscedasticity tests (Sarstedt et al. 2017). Skewness and kurtosis values should remain below 2.58 criteria for normal data distribution. The results of tolerance, variance inflation factor (VIF), and correlation among the explanatory variables confirm that the models are free of multicollinearity issues. Additionally, visual analysis of standardized residuals against predicted value plots is obtained through the Durbin Watson test (1.5 < DW < 2.5) to examine and contrast the homoscedasticity of the data. Altogether 12 OLS models were tested (three for each performance indicator), and the contrast of each model was found significant ($p < 0.000$) as it explains variance by 45%.

Regarding individual and complementarity effect of I4.0TEC and ENVASS on FP of firms, the results represent mixed findings as ENVASS, R, and FPT have a marginally positive effect on SAL, EXP and HLP, and CADM, and DDC have an insignificant or marginally negative effect (see Table 3, model 1 under each performance indicator). In terms of GOM, both ENVASS and I4.0TEC had no significant impact. While physical and human capital appears to have a significant marginal effect on the operating performance of firms which leads us to infer that hypothesis 1 is partially supported. It appears that both ENVASS and I4.0TEC may positively influence the firms’ performance provided these are integrated with firms’ other strategic resources.

The findings of two-complementary effects show coherency with individual effects; ENVASS and R and ENVASS and FPT have a marginally significant positive impact on
Table 2  ANOVA and crosstab statistics of the usage of ENVASS by Malaysian industrial firms

| Variables                                | 2009                                      | 2018                                      |
|------------------------------------------|-------------------------------------------|-------------------------------------------|
|                                          | Unexploited Spent or invested | Spent and invested | Overall | Unexploited Spent or invested | Spent and invested | Overall |
| Firms’ output (thousand RM)              |                                          |                            |         |                            |                            |         |
| SAL                                      | 31,822                                   | 47,503                        | 175,728 | 60,843***                   | 13,802                      | 50,345  | 192,495 | 65,821*** |
| Domestic sales                           | 26,268                                   | 39,385                        | 122,435 | 40,834***                   | 9396                        | 26,450  | 90,340  | 33,932*** |
| EXP                                      | 6656                                     | 29,338                        | 72,384  | 22,645***                   | 4715                        | 22,845  | 101,620 | 34,630*** |
| Added value                              | 5610                                     | 11,410                        | 41,456  | 14,274***                   | 3054                        | 11,458  | 42,943  | 17,482*** |
| Financial assets                         | 31,013                                   | 47,954                        | 356,602 | 76,745***                   | 22,484                      | 44,689  | 173,405 | 82,491*** |
| GOM (%)                                  | 3.1                                      | 6.6                           | 10.3    | 6.3***                      | 7.2                         | 7.5     | 11.4    | 8.5*      |
| Firm inputs (thousand RM)                |                                          |                               |         |                            |                            |         |         |           |
| Capital per employee                     | 66.2                                     | 65.4                          | 250.6   | 102.4***                   | 93.6                        | 113.5   | 152.4   | 113.5***  |
| Workers’ higher educ. (%)                | 12.1                                     | 13.2                          | 18.3    | 19.3*                      | 14.5                        | 18.3    | 21.7    | 22.2***   |
| Worker external training (RM)            | 73.2                                     | 81.3                          | 203.5   | 88.5***                    | 42.3                        | 117.5   | 153.8   | 93.7***   |
| R&D expenditure                         | 198.4                                    | 285                           | 4651    | 4840                        | 543.4                       | 427.4   | 3293    | 832.8***  |
| Innovation and digitization (% firms)    |                                          |                               |         |                            |                            |         |         |           |
| Products                                 | 11.7                                     | 20.7                          | 35.5    | 20.7***                    | 7.4                         | 18.9    | 31.3    | 26.5***   |
| Processes                                | 21.3                                     | 36.6                          | 60.2    | 33.8***                    | 23.6                        | 42.6    | 64.8    | 42.4***   |
| Organizational                          | 15.6                                     | 27.5                          | 52.6    | 25.7***                    | 12.6                        | 25.3    | 40.3    | 28.4***   |
| B2B: digital purchase from supplier     | 26.3                                     | 45.2                          | 55.4    | 33.6***                    | 31.4                        | 48.3    | 57.1    | 42.3***   |
| B2C: sales to end consumer              | 6.8                                      | 6.9                           | 10.2    | 6.4***                     | 9.2                         | 9.4     | 13.8    | 9.5***    |
| B2C: sales to firm                      | 7.9                                      | 10.2                          | 13.3    | 8.2***                     | 6.8                         | 7.9     | 22.4    | 9.5***    |
| Productivity and employment             |                                          |                               |         |                            |                            |         |         |           |
| Productivity                            | 52.1                                     | 50.3                          | 73.5    | 51.4***                    | 47.2                        | 63.7    | 83.5    | 61.4***   |
| Hourly productivity (RM)                | 24.9                                     | 30.2                          | 42.4    | 31.7***                    | 28.4                        | 40.4    | 48.4    | 36.5***   |
| Employees (number)                      | 98.4                                     | 174.6                         | 621.5   | 203.3***                   | 60.2                        | 153.2   | 563.4   | 228.4***  |
| Worker labor cost (RM)                  | 42,817                                   | 45,281                        | 50,342  | 37.843***                  | 31,834                      | 40,948  | 42,450  | 40,340*** |
| Labor cost/ sales (%)                   | 46.7                                     | 31.9                          | 24.7    | 33.6***                    | 33.4                        | 28.6    | 22.4    | 36.4***   |
| N (firms)                               | 738                                      | 728                           | 412     | 832                         | 623                         | 585     | 501     | 833       |
| % firms                                 | 48.7                                     | 31.3                          | 20.0    | 100.0                      | 47.2                        | 30.5    | 22.3    | 100.0     |

*p < 0.1
**p < 0.05
***p < 0.001.

Bolded values represent the percentages of firms higher than the expected values based on normal distribution; standardized corrected residual for counting > 1.9.
Table 3  Results of individual and complementarity effects of ENVASS and I4.0TEC on the performance (indicators of sales, exports, hourly labor productivity, and gross operating margins) of industrial firms in Malaysia

|               | SAL         | EXP         | HLP         | GOM         |
|---------------|-------------|-------------|-------------|-------------|
|               | Model 1     | Model 2     | Model 3     | Model 1     | Model 2     | Model 3     | Model 1     | Model 2     | Model 3     | Model 1     | Model 2     | Model 3     |
| (Constant)    | -7.378***   | -8.302***   | -13.531***  | -13.723***  | -9.346***   | -10.405***  | -6.263      | -5.363      | -4.230      | (2.217)     | (2.162)     | (3.534)     |
| Capital per worker | 1.230***   | 1.284***   | 1.389***   | 1.418***   | 1.259***   | 1.363***   | 1.353***    | 1.285***    | 1.333***    | (0.063)     | (0.039)     | (0.074)     |
| LABCOSTW      | 0.632***    | 0.612***    | 0.587***   | 0.460***   | 0.423***   | 0.487***   | 0.592*      | 0.321**     | 0.214**     | (0.209)     | (0.176)     | (0.235)     |
| R             | 0.193***    | 0.212***    | 0.063**    | 0.047**    | 0.139**    | 0.153**    | 0.160*      | 0.124*      | 0.172*      | (0.073)     | (0.018)     | (0.048)     |
| CAD/CAM (CADM)| -0.053***   | -0.073      | -0.063     | -0.027     | 0.097      | 0.070      | 0.047       | 0.009       | 0.009       | (0.063)     | (0.182)     | (0.014)     |
| DDC           | 0.038       | 0.032       | -0.027     | -0.139     | 0.097      | 0.070      | 0.047       | 0.032       | 0.032       | (0.248)     | (0.189)     | (0.014)     |
| FPT           | 0.204***    | 0.217**     | 0.103**    | 0.097      | 0.084      | 0.070      | 0.047       | 0.032       | 0.032       | (0.063)     | (0.140)     | (0.097)     |
| ENVASS        | 0.206***    | 0.174***    | 0.152**    | -0.138     | -0.138     | -0.138     | 0.073       | 0.064       | 0.064       | (0.073)     | (0.064)     | (0.043)     |
| R×ENVASS      | 0.308***    | 0.260***    | 0.232**    | 0.184      | 0.184      | 0.184      | 0.212       | 0.187       | 0.187       | (0.212)     | (0.187)     | (0.156)     |
| CADM×ENVASS   | -0.085***   | -0.093      | -0.114     | -0.152     | -0.152     | -0.152     | -0.093      | -0.097      | -0.097      | (0.093)     | (0.097)     | (0.102)     |
| DDC×ENVASS    | 0.117***    | 0.125**     | -0.145     | 0.030      | 0.030      | 0.030      | 0.053       | 0.067       | 0.067       | (0.053)     | (0.067)     | (0.052)     |
| FPT×ENVASS    | 0.073***    | 0.083**     | 0.063**    | 0.458      | 0.458      | 0.458      | 0.020       | 0.038       | 0.038       | (0.020)     | (0.038)     | (0.018)     |
| I40TEC×ENVASS | 0.17***     | 0.159***    | 0.112***   | 0.143      | 0.143      | 0.143      | 0.028       | 0.024       | 0.024       | (0.028)     | (0.024)     | (0.019)     |

Summary of the models

|                | N (observations) | Adjusted R² | SE estimates | F-statistics | p-values | Durbin-Watson |
|----------------|------------------|-------------|--------------|--------------|----------|---------------|
| Model 1        | 738              | 0.632       | 2.302        | 197.4        | 0.000    | 1.732         |
| Model 2        | 736              | 0.612       | 2.313        | 187.9        | 0.000    | 1.834         |
| Model 3        | 733              | 0.567       | 2.298        | 212.7        | 0.000    | 1.760         |
| Model 1        | 689              | 0.545       | 1.984        | 216.0        | 0.000    | 1.623         |
| Model 2        | 689              | 0.486       | 1.862        | 159.1        | 0.000    | 1.712         |
| Model 3        | 690              | 0.472       | 1.758        | 144.6        | 0.000    | 1.829         |
| Model 1        | 738              | 0.603       | 2.308        | 214.1        | 0.000    | 1.742         |
| Model 2        | 738              | 0.585       | 2.273        | 195.6        | 0.000    | 1.829         |
| Model 3        | 738              | 0.594       | 2.301        | 234.2        | 0.000    | 1.932         |
| Model 1        | 690              | 0.542       | 2.248        | 123.8        | 0.000    | 1.937         |
| Model 2        | 690              | 0.688       | 2.248        | 223.5        | 0.000    | 1.714         |
| Model 3        | 690              | 0.602       | 2.270        | 195.9        | 0.000    | 1.697         |

Data related to the usage of I4.0TEC was captured every 3 years. The panel data (related to the years 2009, 2012, 2015, and 2018) containing information of new I4.0TEC usage by the firms was updated during OLS estimations for GOM, I4.0TEC, and ENVASS; standardized coefficients and standard errors of the non-standardized effects are presented in parenthesis.

***p < 0.001.
**p < 0.05.
*P < 0.1
while complementarity between ENVASS and CADM has an insignificant negative effect on SAL, EXP, and HLP. It is also notable that complementarity between ENVASS and DDC offers a marginally positive explanation of positive changes in SAL and EXP. Whereas GOM remains constant and represents no effect of complementarities.

Lastly, the effect of joint complementarities of ENVASS and usage of four I4.0TEC on performance indicators is analyzed (see Table 3, model 3 under each performance indicator). The combined effect of the mobilization of ENVASS and higher usage of I4.0TEC indicates a marginally positive effect on the firms’ SAL, EXP, and HLP. Whereas the coefficients of joint complementarity for CADM are lower than the other two complementarities. Moreover, the combined complementarity between ENVASS and aggregate usage of I4.0TEC has no significant marginal effect on GOM. These findings confirm that hypothesis 2 was not supported.

### Estimating combined effect on FP of firms

The findings of OLS estimations in Table 3 consolidated that industrial firms may represent an improvement in FP provided ENVASS and I4.0TEC are integrated with the strategic resources of firms. Hence, this study established an inclusive model of ENVASS, I4.0TEC, and organizational strategic resources, also known as labor cost per worker (LABCOSTW), R&D, and production (Fig. 1). To test this model and the hypotheses proposed within this model, the present study uses the structural equation modeling (SEM) approach which is consistent with the recent

### Table 4: Explanatory factors of the performance of Malaysian firms based on sales, exports, hourly labor productivity, and gross operating margin

| Variables       | Path coefficients (SAL) | Path coefficients (EXP) | Path coefficients (HLP) | Path coefficients (GOM) |
|-----------------|-------------------------|-------------------------|-------------------------|-------------------------|
| H31 LABCOSTW FPI | 0.455*** (0.031)        | 0.453*** (0.029)        | 0.635*** (0.041)        | 0.139** (0.097)         |
| H32 R&D FPI     | 0.382*** (0.026)        | 0.282*** (0.023)        | 0.261*** (0.018)        | 0.225*** (0.134)        |
| H33 PRODFLEX FPI| 0.186*** (0.083)        | 0.162** (0.052)         | 0.363** (0.042)         | 0.062 (0.019)           |
| H34 ENVASS FPI  | 0.589*** (0.062)        | 0.480*** (0.041)        | 0.212*** (0.035)        | 0.114*** (0.076)        |
| H35 R&D I40TEC  | 0.304*** (0.073)        | 0.093*** (0.075)        | 0.308*** (0.056)        | 0.217*** (0.014)        |
| H36 R&D ENVASS  | 0.207*** (0.009)        | 0.203*** (0.015)        | 0.211*** (0.021)        | 0.198*** (0.006)        |
| H37 PRODFLEX ENVASS | 0.063*** (0.020)   | 0.043 (0.039)           | 0.072* (0.073)          | 0.073** (0.023)         |
| H38 I40TEC ENVASS | 0.432*** (0.029)  | 0.472** (0.013)         | 0.531*** (0.062)        | 0.583*** (0.018)        |
| H39 I40TEC LABCOSTW | 0.309*** (0.011) | 0.285*** (0.038)        | 0.218** (0.018)         | 0.187*** (0.031)        |
| H40 ENVASS LABCOSTW | 0.284*** (0.063) | 0.329*** (0.059)        | 0.386*** (0.048)        | 0.373*** (0.042)        |

Model’s goodness-of-fit statistics

| NFI   | 0.956 | 0.973 | 0.978 | 0.988 |
|-------|-------|-------|-------|-------|
| RFI   | 0.940 | 0.956 | 0.961 | 0.955 |
| IFI   | 0.927 | 0.934 | 0.920 | 0.942 |
| TLI   | 0.895 | 0.907 | 0.913 | 0.892 |
| CFI   | 0.923 | 0.938 | 0.926 | 0.915 |
| RMSEA | 0.042 | 0.062 | 0.075 | 0.073 |

FPI consists of sales (SAL), exports (EXP), hourly labor productivity (HLP), gross operating margin (GOM); estimation errors are in parenthesis; goodness-of-fit statistics are measured by normed fix index (NFI), relative fit index (RFI), incremental fit index (IFI), Tucker-Lewis index (TLI), comparative fit index (CFI), and root mean square error of approximation (RMSEA).

***$P < 0.001$.

**$P < 0.05$.

* $P < 0.1$
studies (Diaz-Chao et al. 2021; Ballestar et al. 2020). Table 4 presents the results of standardized coefficients and standard errors of SEM estimates of the performance indicators (SAL, EXP, HLP, and GOM) of industrial firms in Malaysia. The finding of the model’s fitness of good is satisfactory as the values meet the threshold of 1. Furthermore, the RMSEA statistical value is lower or equal to 0.08, validating the estimation model (Hooper et al. 2009).

The values of standardized coefficients predict that human capital, R&D, production flexibility, and ENVASS directly impact SAL, EXP, and HLP. The statistics of GOM indicate that besides human capital, there is a new direct effect between R&D and ENVASS. This finding consolidates ENVASS’ position as the potential contributor to the firms’ profitability as the direct impact of ENVASS is highest on SAL and 2nd highest on EXP, followed by HLP and GOM.

Also, the findings (Table 4) confirm an indirect effect of ENVASS on the performance indicators through their relationship with human capital. This finding leads to establishing that ENVASS are the major instruments of increasing capital in the industrial firms which eventually optimize FP. Pertaining to the predictors of ENVASS in the performance models, expenditure on R&D and the use of I4.OTEC have driven the firms to mobilize their environmental resources. The coefficients of flexible production appear less robust as their values are below the threshold criteria.

SEM technique generates a set of interactions between direct and indirect effects which determines the standardized effect for each explanatory variable (Hooper et al. 2009). The results of path coefficients are presented in Table 4. The results of coefficients are significant and positive for all four explanatory variables which confirm that hypothesis 3 is supported. Hence, it is established that industrial firms may develop their business model combining ENVASS, I4.OTEC, R&D, flexible production, and human capital for better performance. All the coefficients represent relatable total effect (surpassing the effect of I4.OTEC) of ENVASS on the firms’ SAL, EXP, HLP, and GOM. This finding leads to infer that firms with no previous experience in ENVASS may increase their sales, exports, labor productivity, and gross operating margins by mobilizing these resources.

Overall, the results indicate an increasing trend in the mobilization of ENVASS by firms between 2009 and 2018, and the subsequent improvement in the FP for firms can be linked to improvement in ENVASS of firms by spending and investing in these initiatives (Table 2). The expenditure and investment in ENVASS have increased sales, exports, and value of firms as compared to the firms only spent or invested in ENVASS. The individual and complementarity effect of ENVASS and I4.OTEC on FP of industrial firms was determined by estimating the multivariate regression analysis using the OLS technique. Model 1 presents the results of the individual effect of ENVASS and I4.OTEC on FP. The complementarity effect is presented in model 2, and the joint effect of ENVASS and I4.OTEC on FP is outlined in model 3 (Table 3). The results in model 1 delineate that ENVASS, R, and FPT have a marginally positive effect on performance indicators of SAL, EXP, and HLP, while CADM and DDC have an insignificant or marginally negative effect on performance indicators. While physical and human capital has a significant marginal effect on firms’ operating performance, which indicates that H1 is partially supported.

The findings in model 2 of Table 3 determine the two-complementarities effect. The results confirm that ENVASS and R and ENVASS and FPT have a marginally positive (significant) impact on SALE, EXP, and HLP. Whereas ENVASS and CADM have an insignificant negative effect on SAL, EXP, and HLP. The complementarity between ENVASS and DDC also represents a marginally positive impact on SAL and EXP. GOM remains unaffected from the complementarities effect. The results of the joint effect of ENVASS and I4.OTEC on FP determine that effective mobilization of ENVASS and increasing usage of I4.OTEC have a marginally positive effect on SAL, EXP, and HLP (model 3; Table 3). However, coefficients of joint complementarity for CADM are lower than the other complementarities. Also, the combined complementarity between ENVASS and aggregate usage of I4.OTEC shows no effect on the indicator of GOM which confirms that hypothesis H2 was not supported.

The integrated model results (Table 4) reveal that human capital, R&D, production flexibility, and ENVASS have a direct impact on SAL, EXP, and HLP. While the statistics of GOM indicated a new direct effect between R&D and ENVASS which consolidated ENVASS as a potential contributor to the firm’s profitability. Furthermore, ENVASS and its relationship with human capital also represented an indirect effect on performance indicators. The findings of ENVASS as the predictors in the performance models reveal that expenditure on R&D and the use of I4.OTEC have driven the firms to mobilize their environmental resources. Finally, the path coefficients of all four explanatory variables are significant and positive, confirming that H3 and its sub hypotheses were supported.

Discussion and conclusion

This research has extended the recent studies in the literature (Diaz-Chao et al. 2021; Felsberger et al. 2020; Lopez-Gamero and Molina-Azorín 2016; Kanda et al. 2016; Carrillo-Hermosilla et al. 2010) by examining FP of industrial firms based on ENVASS and I4.OTEC. Despite the imposition of stringent industrial regulations for environmental protection and profit maximization, more than half of Malaysian
industrial firms are yet to leverage I4.0TEC and enhance their performance by mobilizing ENVASS. The slow progress toward environmental management practices is havoc as the results of this study have confirmed that firms that actively mobilize their resources (by spending and investing) on developing human capital, R&D, technology, and innovation managed to maximize their sales, exports, and productivity (Birkel and Muller, 2021; Khan et al. 2021). The findings related to GOM between 2009 (economic crises phase) and 2018 (economic recovery and expansion phase) lead to an interesting perspective. The findings explicate the existence of stark differences in the profits of environmentally active and inactive industrial firms during economic crises which can be explained by the environmental premiums (Dangelico and Pontrandolfo 2015). The empirical evidence presented in this research has unique contributions as the extant literature is confined to examining the impact of environmental actions on firms’ profitability (Arda et al. 2019; Ryszko 2016; Ramanathan 2018); however, the results of this study offer a linkage between environmental actions, economic cycles, and firms’ profitability. This prospect can facilitate the firms in the future to identify the spillover effects ushered by environmental actions on firms’ efficiency and profitability, which will provide a toolkit for tackling the transformation process during future economic crises (Beltrami et al. 2021; Gerstlberger et al. 2016).

Another unique contribution of this research is statistical analysis delineated the linkage between ENVASS, I4.0TEC, and FP by going beyond the conventional approaches. The findings presented in Table 3 analyzed the individual and complementarity effect on the performance indicators (sales, exports, labor productivity, and gross operating margin). These findings partially confirmed hypothesis 1, whereas hypothesis 2 was rejected. The positive results of the findings of individual effect represented that ENVASS, usage of robots, and flexible production technologies have a marginally positive impact on sales, exports, and labor productivity. Similarly, the findings of two complementarity effects confirmed that usage of robots and ENVASS and flexible production technologies and ENVASS has a marginally positive impact on sales, exports, and productivity; data-driven control and ENVASS have a marginally positive impact on sales and exports; the joint complementarities of ENVASS and the usage of I4.0TEC resulted in a marginally positive impact on sales, exports, and productivity. The negative results of the individual effect (Table 3) indicate that computer-aided design and manufacturing and data-driven control have an insignificant marginal impact on sales, exports, and labor productivity. Similarly, the gross operating margins of the firms remain unaffected from ENVASS and any I4.0TECH. The negative results of the two complementarity effects found that computer-aided design and manufacturing and ENVASS failed to have any significant impact on sales, exports, and productivity; none of the complementarities had any significant impact on gross operating margin. Although joint complementarities were established between ENVASS and I4.0TEC for sales, exports, and productivity, the coefficients of joint complementarities were less than the sum of individual coefficients. Finally, none of the joint complementarities had any significant impact on gross operating margin.

The findings of this study are compatible with the studies of Porter and van der Linde (1995) and Adams et al. (2016), which corroborated that firms spending and investing in green initiatives may enhance their performance by mobilizing ENVASS to save cost and boost productivity (Doran and Ryan 2016; Fang and Zhang 2018; Felsberger et al. 2020; Ferron-Vilchez and Darnall 2016) as it accelerates the volumes of sale and export (Ambec and Lanoie 2008; Lo et al. 2012; Delmas and Pekovic 2013). The results of the use of I4.0TEC are also consistent with the studies of Dalenogare et al. (2018) and Brozzi et al. (2020), confirming that environmentally driven firms may increase their sales, exports, and productivity through robotization, flexible production technologies, and the usage of data-driven control to some extent. The findings of this research have also consolidated the narratives of past studies of Ghisetti and Rennings (2014), Ozuasaglam et al. (2018b), and Rexhauser and Rammer (2015), claiming that combined use of I4.0TEC with ENVASS can help industrial firms in maximizing their sales, exports, and productivity. Whereas, the findings of complementarity between environmental actions and technology and its impact on cost supports the rejection of Porter’s hypothesis recommending firms to avoid the extra cost to go green (Ozuasaglam et al. 2018a; Horvathova 2012; Mithani 2017). Lastly, the results related to the complementarities between I4.0TEC and ENVASS are consistent with the recent study of Beltrami et al. (2021), Diaz-Chao et al. (2021), and Felseberger et al. (2020) which found that certain I4.0TEC such as computer-aided design and manufacturing have a marginal impact on the performance of industrial firms.

This study has developed a performance measurement model for industrial firms to expand the discussion related to the performance of firms under the combined effect of ENVASS and I4.0TEC. The model was developed by integrating R&D, organizational flexibility, and human capital management, which aligns with the approaches of recent studies (Diaz-Chao et al. 2021; Felseberger et al. 2020; Singh et al. 2020; Yunus 2020). The findings of the developed model confirmed that ENVASS, I4.0TEC, R&D, flexible production, and labor cost per worker have a significant positive impact on all the indicators of performance, including gross operating margin.
The ecosystem of industrial firms has experienced radical transformations due to the emergence of innovative technologies such as I4.0TEC (Birkel and Muller 2021; Felsberger et al. 2020; Khan et al. 2021a). This has escalated expectations of the industrial sector in terms of improvement in financial performance. The concept of sustainability in the industrial sector advances the implementation of a series of innovative technologies as these innovations are confirmed as the significant booster of firms’ profitability and environmental sustainability (Beltrami et al. 2021; Jabbour et al. 2020; Sharma et al. 2020). The integration of I4.0TEC with the mobilization of ENVASS and other dynamic sources enhances the economic position of firms and justifies the usage of green mechanisms to transform the business models during unprecedented situations such as economic and pandemic-type crises (Diaz-Chao et al. 2021; Felsberger et al. 2020).

The findings of industrial firms have confirmed that individual and complementary linkages have a partial impact on firms’ FP. The optimistic context of the findings predicted that individual and complementarities of ENVASS, robotics, and flexible production technologies improve sales, exports, and labor productivity. While the less conducive aspect of the findings dictates that certain technologies such as computer-aided design or manufacturing have no impact on performance as well as the profitability of firms cannot be explained by the interaction between I4.0TEC and ENVASS. This is further explained by developing a model by integrating ENVASS, I4.0TEC, spending and investing on R&D, production flexibility, and human capital management. This model confirms the significant impact of I4.0TEC and ENVASS on the FP of firms, especially to the indicator of gross operating margin.

Validating environmental and business implications

The creation of a robust business model connecting environmental initiatives and I4.0TEC with the economic performance of industrial firms has two potential implications. Firstly, it authenticates the challenges faced by the firms and the mobilization of strategic, technical, human, and operational resources (Ervin et al. 2013) to grab the low-hanging fruits of environmental actions. The proposed model in this research outlines that environmental and human capital, technological innovations (R&D and I4.0 technologies), and firms’ operational schemes (production flexibility) surpass the dynamic capabilities. These exclusive capabilities offer sustained competitive advantage to the firms (performance matrices) (Eisenhardt and Martin 2000; Teece 2007, 2016; Kraaijenbrink et al. 2010) by transforming production systems and restructuring human physical capital. These capabilities authenticate the implication of DCV as the conceptual framework of this study to develop an economically viable business model by integrating ENVASS (Teece et al. 1997; Amui et al. 2017). However, achieving competitive advantage through sustainability requires further strategic and organizational resources which need to be studied further (Pohl et al. 2019).

The prospect outlined in this research about environmental capabilities and dynamic resources can be associated with the circular business models (Bag et al. 2021; Urbinati et al. 2017; Kirchherr et al. 2017). The evidence presented in this study advances that the nexus between I4.0TEC and sustainability optimizes the usage of dynamic capabilities (Rosa et al. 2020; Sharma et al. 2020). The proposed value creation model for industrial firms may complement the use of dynamic environmental capabilities. The findings of this research can be extended by adding other organizational capabilities and strategic resources to obtain a rigorous economic, social, and environmental prospect (Murray et al. 2017).

Managerial, strategic, policy, and crises implications

The results of this study have several managerial, strategic, and public policy implications during economic crises ushered by the current global pandemic of Covid-19. Even though recent studies have linked the climate emergency with the recent health crises (Contini et al. 2020; Wu et al. 2020b; Johnson et al. 2020), however, the delay in the implementation of environmental strategies will further deepen the economic and health crises. The relative justification in this context is businesses and governments are delaying the environmental sustainability for economic and social sustainability. Whereas, the findings of this study have just highlighted that developing a sustainable business model may result in a better economic performance which can be achieved by leveraging I4.0TEC, spending and investing in R&D, flexibility in production, and proper management of human and environmental capital. Consequently, the developed business model signals a payoff for going green which represents the triple bottom line approach of sustainability. Managers and public policies need to address and revolve around these three paradigms of ENVASS (technology and environment), social (management of human capital), and economic (performance) while creating a win–win strategy. Therefore, regulating the firms’ environmental and strategic resources is essential and enhancing access to public and private innovative ecosystems.

Limitations and future research

The theoretical, statistical, and analytical approaches deployed in this study have certain limitations which should be addressed by prospective studies. The first limitation is related to the use of dichotomous variables to analyze environmental resources and I4.0TEC. The researchers were restricted to using this scale to measure the mobilization of economic and financial resources through spending and investing due to a
lack of direct information on investing and spending on environmental initiatives. Similarly, I4.0TEC was also measured using a similar approach as there was no specific information related to the consolidation of I4.0TEC such as the Internet of Things and big data. Even though the use of a dichotomous scale is justified, future studies may consider developing better indicators to measure environmental actions and I4.0TEC to obtain accurate economic, social, and environmental results.

Second, the scope of this research was limited to industrial firms in Malaysia which have adopted environmental management schemes and I4.0TEC. Future studies may expand the scope of research by adding firms from other sectors such as the service sector, creating a composite sustainability index for economies in developing countries. Third, the researchers have exclusively addressed the biasness of results through robustness checks; however, future researchers may consider additional statistical estimates to ensure the complete robustness of results. Finally, the results of this study can only be generalized and used to estimate the impact of I4.0TEC and ENVASS on the FP of firms with 250 to 500 employees. Future studies may consider large firms having more than 500 employees to improve the theoretical and practical generalizing aspect.

**Author contribution** Conceptualization: Q.A.; formal analysis: Q.A.; investigation: Q.A., H.Y., and S.P.; methodology: Q.A., A.S., Z.Z., and H.Y.; supervision: Z.Z. and A.S.; writing – original draft: Q.A.; writing – review and editing: Q.A., S.P., H.Y., Z.Z., and A. S.

**Data availability** The datasets/materials used and/or analyzed for the present manuscript are available from the corresponding author on reasonable request.

**Declarations**

**Ethics approval** Not applicable.

**Consent to participate** I am free to contact any of the people involved in the research to seek further clarification and information.

**Consent for publication** Not applicable.

**Conflict of interest** The authors declare no competing interests.

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