Operations Management Research
https://doi.org/10.1007/s12063-021-00226-8

Digital technologies as enablers of supply chain sustainability in an emerging economy

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Received: 4 May 2021 / Revised: 15 September 2021 / Accepted: 18 October 2021

Abstract
Vietnam is a country with significant potential for growth as a global centre for manufacturing, as supply chains look to reduce their over-reliance on China in the aftermath of COVID-19. The objective of this study is to better understand the current adoption rates and growth potential of emerging Industry 4.0 (I4.0) digital technologies and ascertain their potential to drive successful future sustainability initiatives amongst Vietnamese supply chain firms. These technologies offer a wide range of sustainability benefits, from a potential to reduce waste production and lower energy consumption to increased opportunities for recycling and industrial symbiosis. This empirical study surveys 223 Vietnamese supply chain experts to learn how digital technologies are being utilized in that region, what levels of future investment are expected, what preparatory measures are being taken to leverage new technologies, and what scope for improved supply chain sustainability exists. The findings indicate a low level of I4.0 digital technology adoption amongst Vietnamese supply chain firms, with the Internet of Things (IoT) currently being the most prevalent (48 percent adoption rate). Drones, Big Data Analytics and IoT are the I4.0 digital technologies expected to have the greatest future impact on Vietnamese supply chains. Whilst I4.0 digital technology adoption is still at this early stage, that may present a greater opportunity for driving future sustainability outcomes, than interrupting and retrofitting solutions to already-established networks and infrastructure.

Keywords Supply chain sustainability · Internet of things (IoT) · Industry 4.0 · Artificial intelligence (AI) · Big data analytics (BDA) · Sustainable development · Circular economy

1 Introduction

The sudden emergence of the COVID-19 coronavirus caused havoc on a global scale for supply chains (Queiroz et al. 2020), forcing factories to close, restricting the movement of freight, and bringing cities around the world into lockdown (Hopkins 2021; Inoue and Todo 2020; Paul and Chowdhury 2020). The aftermath of large-scale disruptions like this often signals the need to reflect and rethink future business plans, including opportunities to improve supply chain sustainability, support Cleaner Production (CP), and achieve greater commitment to Circular Economy (CE) strategies (Jan 2020). The recovery process, to build a sustainable future for the planet in the aftermath of such a severe shock, will require "system-based thinking that involves, in equal measure, society, environment, and economics" (Murray et al. 2017, p. 377).

The importance of sustainable practices were growing long before COVID-19, due to an increasing and wider appreciation for these three dimensions of sustainability; environment, society, and economy (Akbari and McClelland 2020). Supply chains shifted focus toward achieving sustainability goals through business collaborations, connectivity, partnerships, innovation, real-time monitoring and control, and CP. Successful management of supply chains has come to recognize these changes (König and Spinler 2016), and a commitment towards CP offers numerous opportunities for improved sustainability, progressing an ethical outlook of corporate social responsibility, corporate citizenship, and equity for a sustainable society (de Man and Strandhagen 2017).

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Published online: 11 May 2022

As part of this growing commitment, supply chains have increasingly sought new and alternative methods to implement sustainability and enhance resource efficiency (Pagoropoulos et al. 2017). The CE is a systematic approach to economic growth which considers sustainable environmental and economic development (Korhonen et al. 2018), and places emphasis on the replacement of polluting components and materials, saving natural resources, dismantling, remanufacturing, refurbishing, reuse, recycling, and the possibility of rebirth at the end of the product life cycle (Agyemang et al. 2019).

Digital technologies will also play an important role in the COVID-19 recovery, with a greater focus on digitalization and automation being anticipated, as supply chains "increasingly look towards digital technologies as sources of innovation in the wake of an extreme disruption" (Hopkins 2021, p. 1). Industry 4.0 (I4.0) focuses on smart manufacturing and automation systems, driven by the application of the latest technologies, with the potential to support sustainability practices and CE concepts (de Sousa Jabbour et al. 2018a). A global survey by Deloitte (2018), discovered a number of ways in which I4.0 technologies are already being used to support sustainability practices in today's supply chains, by minimising external environmental impacts (e.g., reducing energy and water usage), reducing discretionary travel, formulating better usage of recycled and repurposed supplies, and promoting safer workplaces by shifting dangerous and repetitive tasks from human operators to automation and robotics. However, I4.0 technologies are not widely available in many developing countries, and little is known about their adoption rates, challenges, and opportunity potential (Jabbour et al. 2020).

In the last decade, Vietnam's economy has progressed rapidly and established itself as the fastest developing country in South East Asia, attracting a huge amount of Foreign Direct Investment (FDI) and making it a region of significant global importance for academic investigation (Akbari and Ha 2020). Currently, the entire world is economically impacted by the COVID-19 epidemic, which has also caused significant disruption to global supply chains. However, Vietnam was one of the first countries which managed to control the pandemic and progress toward post-COVID-19 recovery. Vietnam News (2020) predicts that the total amount of FDI will be US$38.6 billion post-pandemic with companies such as Foxconn, Apple's key manufacturing partner, already planning to invest $270 M in manufacturing facilities in Vietnam (Jennings 2021).

The objective of this exploratory research is to better understand the current adoption rates of emerging I4.0 technologies amongst Vietnamese supply chain organizations and to ascertain their potential for driving future sustainability initiatives. Examples of this line of inquiry are currently lacking in the existing body of academic knowledge, and it is hoped that the results from this research will provide insights into the underlying challenges and opportunities faced when adopting these digital technologies, and inform future education and training needs for supply chain practitioners.

To achieve this, the researchers will endeavour to address the following research questions:

RQ1: To what extent have emerging Industry 4.0 technologies already been adopted by Vietnamese supply chain firms?
RQ2: How will emerging Industry 4.0 technologies support supply chain sustainability and in Vietnam over the next decade?

This paper is structured as follows. Section 2 reviews current discourse in the areas of supply chains, CP, CE, I4.0 and the emerging technologies being utilised today. Section 3 details the adopted research method, whilst Sect. 4 presents survey results from the primary data collection. Section 5 presents and discusses the key theoretical and practical implications of the research, and Sect. 6 concludes by highlighting avenues for future studies, alongside some of the limitations of the study.

2 Literature review

Sustainability and I4.0 are both key focal areas for today's supply chains (de Sousa Jabbour et al. 2018a), which can be aligned to address a number of the United Nation's (UN) Sustainable Development Goals (SDGs), and the adoption of emerging technologies is regarded as a critical component for the realisation of many sustainable practices, such as CP and the concept of a circular economy (CE) (Jin et al. 2017).

The following section will review the existing body of academic literature in this field and define all the key research terms in greater detail. We define SCM, CP, CE and I4.0, and discuss why Vietnam is a significant region for this type of research. Later in the section, we explain the research framework that was adopted for this study.

2.1 Supply chain management

Supply chain networks spanning international borders have been one of the major driving forces behind globalization (König and Spinler 2016). As a result, supply chains have needed to become more robust, complex, and costly (Akbari and Do 2021). Supply chains support the end-to-end production of goods and/or services, from raw materials to the delivery of finished products to end customers around the world and offer many opportunities for improved sustainability throughout, from improved strategic purchasing (Vargas et al. 2018) to the adoption of more sustainable transport (Halldórsson et al. 2010).

Supply chains are also changing the way organizations connect, collaborate, and share information (Hopkins 2021). Therefore, any move towards increased digitalization in supply chains can offer significant opportunities for change. Adopting new technologies often drives digitalization (Waller and Fawcett 2013), impacting many functions across supply chains, including procurement, manufacturing, logistics, warehousing, inventory management, retailing, and supplier and customer relationships (Hofmann and Rüsch 2017).

In today's landscape, the adoption of digital technologies where supply chains compete against other supply chains is increasingly important to remain competitive (Akbari and Do 2021). Consequently, SCM has entered an era where leveraging emerging I4.0 digital technologies is necessary to enable data-driven decision-making, transform business processes, and support innovative changes in manufacturing, transportation, and warehousing (Abbasi et al. 2016). Organizations have already recognized the significant impacts of innovative digital technologies, as enablers of sustainable initiatives, and for improving supply chain performance (Fuchs 2008). They benefit network design and delivery improvement, optimization and reduction in touchpoints, bottlenecks and cycle time reduction, leading to improved supply chain agility and resilience.

As globalization continues to grow, so has an increasing global awareness of its impact on the environment, society, and economy (Fiorini and Jabbour 2017). The balance between environmental, social and economic dimensions is defined as sustainability (Seuring et al. 2008). Thus, the adoption of sustainable practices with a greater focus on CP need to be considered, and supply chain managers must be adequately prepared.

2.2 Cleaner production and circular economies

CP is concerned with using less energy and materials, and the efficiency and substitution of harmful products and materials, with less dangerous ones (Hens et al. 2018). According to the United Nations' Environment Programme (UNEP/IEO 1990), CP is considered as the continuous application of integrated preventive environmental strategies for products, and services that improve efficiency and reduce damage to humans and the environment. CP and CE concepts are closely linked as appropriate sustainability models (Tseng et al. 2013).

The CE is widely regarded as a viable business approach for sustainable development (McDowall et al. 2017). The CE offers a new supply chain perspective on production and consumption by focusing on restoring, or recycling, the value of used resources (de Sousa Jabbour et al. 2018b). The full adoption of CE raises challenges for supply chains, such as a lack of information regarding product life cycles, the recovery of used products, and a shortage of advanced technologies (Su et al. 2013). With the increasing sophistication of today's digital technologies, the concept of CE is now more feasible than it has been in the past (de Sousa Jabbour et al. 2018b). The CE is based on a combination of biological and technical cycles (Table 1).

A leading global charity, the Ellen MacArthur Foundation, has proposed six business actions called the "ReSOLVE" framework (MacArthur et al. 2015) to guide the implementation of CE (Table 2):

I4.0 technologies have the potential to significantly affect sustainability development (Bai and Sarkis 2020). Therefore, supply chain practitioners must take into account the contribution of I4.0 technologies to sustainability, CP and CE.

2.3 Industry 4.0 technologies

The term Industry 4.0 has been globally adopted to describe the 4th industrial revolution, the development of cyber-physical systems to enable smart factories and autonomous systems (Lee et al. 2015a). The latter is predicted to create significant disruption to the future global trade and supply chains (Piccarozzi et al. 2018). The main drivers of I4.0 are the emergence of a number of key digital technologies, but no single definition currently exists for the exact set of digital technologies which constitute I4.0 (Hopkins 2021). In the absence of this, the technologies selected for this research were chosen based on those most commonly appearing in academic literature, industry white papers and online forums, at the commencement of the research (Table 3). The technologies forming the focus of this research are; 3D Printing (3DP), Advanced Robotics, Artificial Intelligence (AI), Autonomous Vehicles, Big Data Analytics (BDA), Drones, Internet of Things (IoT), Blockchain, and Virtual Reality/Augmented Reality (VR/AR).

Virtual Reality (VR) and Augmented Reality (AR) are technologies that offer the potential to educate and train, visualize products, and create virtual work environments (Azuma 1997; Steuer 1992). This improves connection among stakeholders as well as pro-environmental behaviour stimulation regardless of their physical location (Hopkins

Table 1 Circular economy (CE) cycles

CE Cycles	Description
Biological Cycle	Regeneration of ecosystem, such as reducing excessive extraction of natural resources, reusing energy, or using renewable energies (MacArthur et al. 2015)
Technical Cycle	Extension of product lifespan, such as ruse, repair, refurbishment, remanufacturing, recycling (Bocken et al. 2017; Murray et al. 2017; Zhao and Zhu 2015)

Table 2 ReSOLVE framework and relationship to industry 4.0

Business Action	Description	Technology Link
Regenerate	Biological cycles are used to shift to renewable energy and materials	IoT, BDA, AI, AVs, Drones
Share	Goods, assets, and losses are shared between individuals	IoT, AI,
Optimise	Technology-centered strategy to reduce the waste across supply chains	IoT, DBA, AI, AVs, Robotics, Drones
Loop	Biological and technical cycles to recapture and/or restore the organic and post-consumption values	IoT, AI
Virtualise	Service-focused strategy to replaces physical products	VR/AR, IoT
Exchange	Substituting non-renewable goods with renewable ones	3D Printing or Additive Manufacturing

and Hawking 2018). In the post-COVID-19 era, when working from home and e-commerce become significantly more common, the demand for virtual work and a collaborative environment will almost certainly increase.

BDA provides a critical success mechanism for SCM (Hazen et al. 2016; Tan et al. 2015). Supply Chains generate huge amounts of data, ranging from the point-of-origin, to the point-of-consumption (Wang et al. 2016). BDA supports better-targeted marketing, improved forecast accuracy and predictive analysis, thereby increasing agility, customer focus, and an improved recognition of marketing and sales opportunities (Karimi et al. 2019). BDA also support new business models for CE (Jabbour et al. 2019). All these factors have a great impact on sustainable initiatives (Akbari and Do 2021; Hazen et al. 2016; Wang et al. 2016).

Artificial Intelligence focuses on the ability of machines to demonstrate some intelligence similar to animals/humans. Advances in AI can enable real-time fraud and management of associated risks (Lotakov 2016), better inventory placement (Frommberger et al. 2012), energy efficiency (Jahanshahi et al. 2020) and reduce human involvement in the workplace. It has been predicted that AI will disrupt more than 30 percent of existing tasks by many occupations in the USA (McKinsey 2017).

Autonomous Vehicles (AVs) integrate technologies across the global supply chain, as part of the evolutionary step toward digital supply chain networks (Bechtsis et al. 2018), and one of the great impacts of this technology is long-haul autonomous trucks (Abbott et al. 2018). The implementation of these vehicles promises to reduce the total shipping cost, the number of accidents, fuel consumption, and greenhouse gas (GHG) emissions and reduce labour costs (i.e., driver wages) (Bonnefon et al. 2016; Zamani et al. 2019).

3DP or Additive Manufacturing (AM) were used in the past to prototype new products, while today promise great future volume/variety trade-off in manufacturing (Bozarth and Handfield 2008), where smaller volume and user customization is the main focus (Weller et al. 2015). There are many benefits for adopting the technology, such as dematerialization of physical goods (Vendrell-Herrero et al. 2017), resulting in cost reduction in transportation and storage, last-mile delivery improvement (McKinnon 2016), shorter product life cycles (Rehnberg and Ponte 2018), cost-sharing from manufacturers to the end-customers (Rayna and Striukova 2014), energy-saving and CO2 emission reduction (Gebler et al. 2014). 3DP also has the potential to significantly disrupt the spare parts market (Rehnberg and Ponte 2018).

Table 3 Summary of literature related to emerging technologies

Technology	Description	Reference
Virtual Reality (VR) and Augmented Reality (AR)	VR—allows users to connect to sensible electronic simulations	(Steuer 1992)
	AR—ability to adapt virtual 3D objects into real surroundings	(Azuma 1997)
Big Data Analytics (BDA)	Large sets of data that was not possible to analyze or use with the traditional business tools	(Cox and Ellsworth 1997)
Artificial Intelligence (AI)	Branch of computers attempting to imitate human intelligence	(Miles and Walker 2006)
Autonomous Vehicles	Intelligent capable vehicles that motion to any unexpected situation from their environments	(Hagen et al. 2007)
3D Printing (3DP) (Additive Manufacturing)	Creating a 3D physical object from digital data	(Bozarth and Handfield 2008)
Internet of Things (IoT)	Interconnected objects in an articulated intelligence network with sensing technologies	(Yang 2014)
Advanced Robotics	Electrical machinery to support humans and automation processes	(Eckert et al. 2016)
Drones	Micro aerial vehicles for delivery, surveillance, and many more	(Nentwich and Horváth 2018; Schröder et al. 2018)
Blockchain	A decentralized system storing all transactions permanently	(Francisco and Swanson 2018)

Internet of Things (IoT) connects physical devices, such as sensors, pumps, washing machines, air conditioners, fridges, water meters, lights, thermometers and RFID tags, to the digital environment via standard communication (Wortmann and Flüchter 2015). With an increasing number of sensors fitted in many aspects of transportation, this field of technology is predicted to significantly impact supply chains (Zhou et al. 2012). Implementation of IoT benefits the supply chain with real-time tracking, tracing, predictive maintenance approach, accurate forecasting, and sales data, customized marketing, waste control and overproduction, better achievement in sustainability practices, and increasing the opportunity for the reuse and recycling of waste products/packaging, and industrial symbiosis (de Vass et al. 2021; Nagy et al. 2018; Shirmohammadi et al. 2017).

Advanced Robotics provides a common approach in manufacturing and warehousing (Krueger et al. 2016) for improved efficiency in material handling, picking and packing, welding and inspection, removal of intensive and repetitive labour, cost reduction, energy saving, safer and sustainable work environment (Ganesan et al. 2017). Increases in automation more broadly, reduce the overall requirement for human presence, resulting in emissions and energy savings due to reductions in commuting (Moglia et al. 2021).

Drones were originally designed for military purposes but have emerged as a prospective solution to supply chain challenges such as urban parcel delivery, stockpiling, surveillance, inspection vehicle, traffic congestion, and pollution (Nentwich and Horváth 2018; Schröder et al. 2018).

Blockchain provides a developed and recognized decentralised system, where any transactions will be stored and recorded permanently, including a timestamp component (Cole et al. 2019; Sivula et al. 2021). This significantly improves collaboration, accuracy, transparency, and security in supply chains (Rogerson and Parry 2020). The sustainability impact of this system (Kouhizadeh et al. 2021) can involve revolutionizing supply chain operations for product traceability [i.e., Maersk (Popper and Lohr 2017) and Provenance (Baker and Steiner 2015)], enhancing sustainability [i.e., cashmere in Mongolia (Huang 2019)], and ensuring food safety [i.e., Chipotle Mexican Grill (Casey and Wong 2017)].

These technologies are predicted to lead supply chains toward the creation of a smarter, better-connected, platform-enabled ecosystem (Schrauf and Berttram 2016), which facilitates the ability to support resource, energy, and transport savings (Fuchs 2008). They promote CP practices, removing waste throughout the supply chain through improved planning, designing, operating, and management of supply chain activities (Klemeš et al. 2012), and support many of the closed-looped supply chain dynamics required to create a more promising CE concept (Tunn et al. 2019).

2.4 Vietnam as the region of focus

Over the past few decades, Vietnam has achieved significant growth due to the Đổi Mới (Renovation) economic reforms in 1986 (Cameron et al. 2019). It has emerged from one of the poorest countries in the late 1970s (Clarke et al. 2017), to become one of the most attractive countries for foreign investors in 2020 (Vietnam News 2020), especially during the post-COVID-19 era (Asian Development Bank 2020). Vietnam, as the most dynamic emerging country in the East Asia region (World Bank 2021), has experienced significant development in manufacturing and is currently the second-largest rice and coffee producer in the world, a top-ten garment exporter, a leading furniture manufacturer and exporter, and a hot spot for high-tech manufacturers such as Samsung, Intel, IBM, Nokia, and Canon (Nguyen and Robinson 2015).

Currently, Vietnam is one of the fastest-growing economies in the region, with a 2019 GDP growth of 7 percent, and a GDP of $6,776 per capita (World Bank 2021). The country stands 48th in the Human Capital Index (HCI), second only to Singapore in the Association of Southeast Asian Nations (ASEAN) region. The population of Vietnam is approximately 96.9 million, 34.4 percent of whom live in urban areas (General Statistics Office of Vietnam 2019). The national employment rate in Vietnam is more than 75 percent (Table 4).

Table 4 Economic indicators and population of Vietnam in 2019/2020

Population (Total)	Population Age	Annual Change in Population	Internet Users	Median Age	Urban Population	GDP per Capita	Mobile Subscription
96.9 Million **Ho Chi Minh City** 8.99 Million **Hanoi** 8.05 Million **Female** 50.2% **Male** 49.8%	70% < 35 years old	+0.9% (+896 thousand)	64 M (66% penetration)	32.5 years	33.1 M (34.4%)	$6,776	143.3 Million

Sources: General Statistics Office of Vietnam (2019), and World Bank (2021)

Vietnam is a responsible member of the United Nations and has been actively participating in the global sustainable agendas, and the Sustainable Development Goals (SDGs) (Medium Corporation 2017) was implemented as the National Action Plan to employ the 2030 Agenda for SDGs (UNSD 2018). The country prepared a Voluntary National Review (VNR), which aspired to assess the successes of the 2030 Agenda and 17 SDGs.

The next section presents the adopted research framework, and describes the drivers which encourage supply chains to embrace I4.0 technologies, in the pursuit of sustainability goals.

2.5 Research framework

This empirical study aims to collect primary data concerning the current adoption of I4.0 and its related preparation measures, to better understand the future impact of emerging technologies on sustainable supply chains in Vietnam. Figure 1 highlights the role of I4.0 technologies, and the potential benefits they offer supply chain networks, for driving sustainability improvements. Embedding technologies such as AI, Big Data and IoT, for example, can have significant upstream and downstream benefits for supply chains, and the adoption of I4.0, with the correct preparatory measures, can lead to improved supply chain sustainability in emerging markets like Vietnam.

3 Materials and methods

This investigation follows a 3-step approach, to examine the concept of digital transformation for improved sustainability outcomes and establish the current adoption patterns for I4.0 technologies in Vietnamese supply chains, as a mechanism for guiding future research (see Fig. 2).

Step 1: Seuring and Muller (2008) state that the foundation of every study is emergent from a literature review which enhances understanding and conceptualisation of the topic at hand. Accordingly, a literature review was performed to process this investigation systematically and comprehended the existing related research area (Fink 2014).

Step 2: A descriptive survey was employed for data collection as the most appropriate method for this research. Descriptive surveys are the most effective method for studying and collecting information from specific populations regarding their opinions, attitudes, preferences, and characteristics (McMurray 2004). While this method does not necessarily claim or establish causal relationships, it is an effective mechanism for collecting primary data for the basis of future planning and informed decision-making processes (Chisnall 1993).

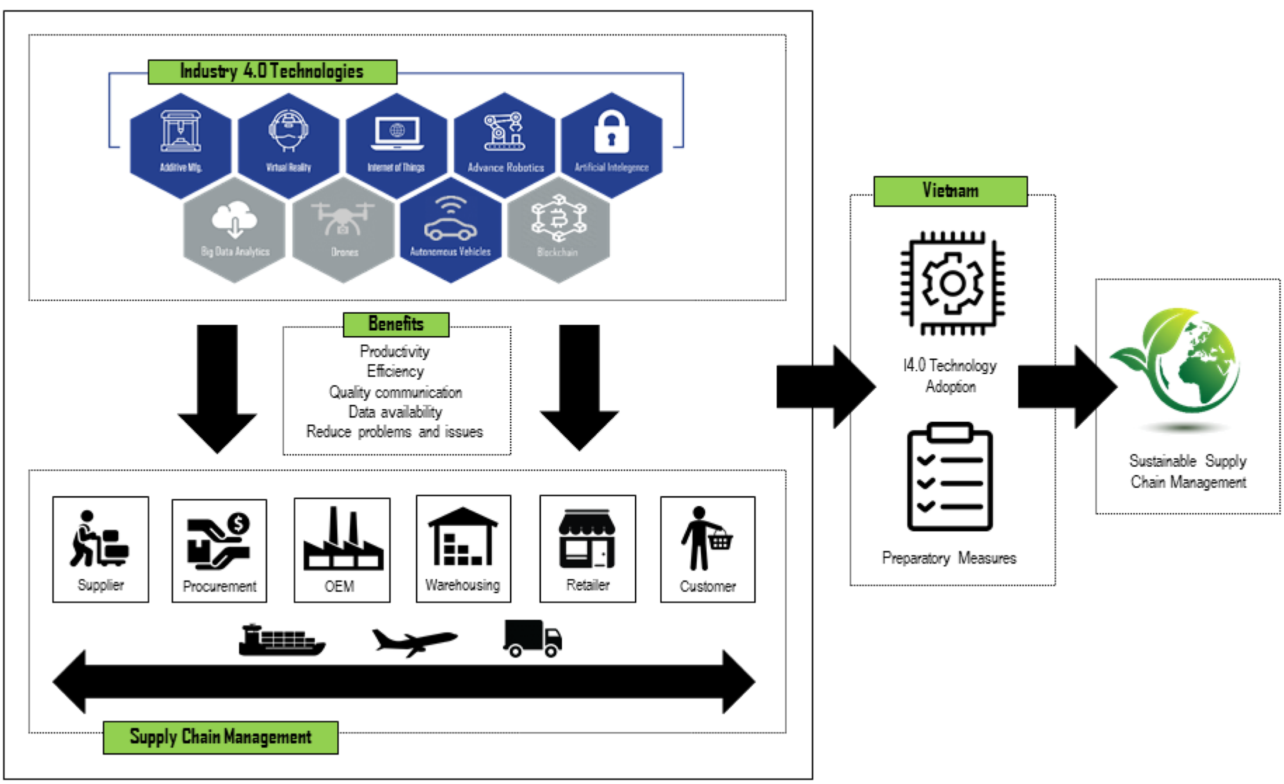


Fig. 1 Research Framework (*Adapted from* Akbari (2018); Hopkins (2021); Wisner et al. (2012))

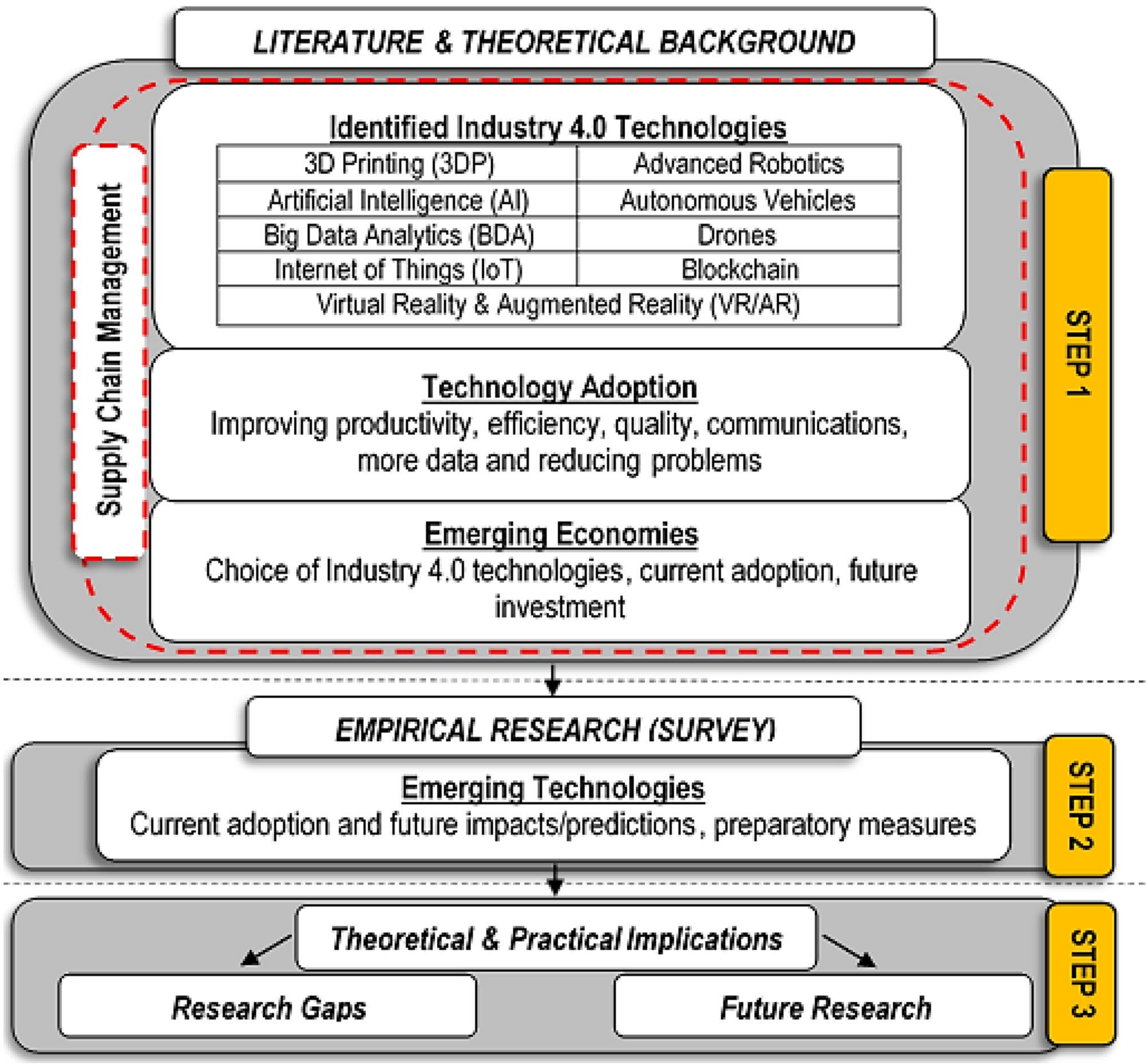


Fig. 2 Research Steps and Methodology (*Adapted from* Akbari and Hopkins (2019); Rüßmann et al. (2015))

The most appropriate method for this research was chosen to be a descriptive online survey questionnaire. Online surveys give researchers the ability to access wider populations in an efficient and speedy manner. Similarly, they are convenient for participants and provide a robust and cost-effective option to attain higher response rates (Yin 2003; McMurray 2004). In the case of this present study, an online survey was created and hosted on the Qualtrics platform, which enabled the researchers to connect directly and simultaneously to supply chain professionals spread across Vietnam.

Descriptive research enables a phenomenon to be studied in-situ, within its natural context (Yin 2003) and is concerned with the 'what' rather than the 'why.' As such, this method is ideal for studying specific groups and extracting personal opinions, beliefs attitudes, and predictions (McMurray 2004). It offers the investigator a 'snapshot' of a phenomenon at a particular point in time, from which inferences can make (Galliers 1990). It doesn't suggest the existence of causal relationships but is a suitable method for collecting new data about specific phenomena, from which valuable observations can be made (Chisnall 1993). The survey consisted of 74 questions, including a combination of multiple-choice, Likert-scale, drop-down lists, rank order and matrix table, and was administrated in late 2019 (Table 5).

Table 5 Summary of survey questions

Demographic Information	Gender, Age, Salary, Working industry, Job position, Company size
Current adoption	Current adoption rates of digital technologies, current preparatory action taken for the development of digital technologies, Concerns about each developing/emerging technology
Future impact/predictions	Predictions regarding the impact of digital technologies on firms and/or sectors, Predictions to the level of investment over the next 10 years

The online survey tool Qualtrics was used as the research platform for this study. Utilising the 2020 VNR 500 directory (VNR500.com.vn), a list which names the nation's 500 largest enterprises each year, appropriate supply chain companies were identified based on their background, histories and region of operation. The directory enabled the authors to filter specifically for supply chain companies and remove all non-relevant organizations from the sample. A total of 500 invitations were sent to CEOs, directors, and senior managers, with a useable response rate of 45 per cent (n = 223). The study applied a range of analytical techniques such as descriptive statistics, cross-tabulation, correlation, and regression approaches. The Relative Importance Index (RII) was employed as a proven method to identify the importance (Akbari 2013), where *W* is the given weight, *A* is the highest weight, and *N* is the total population.

$$RII = \sum W/A \times N$$

Cronbach's alpha reliability test resulted in a score of 0.802 to assure the reliability of the variables "current adoption" and "future impact" of the emerging technologies.

Step 3: The findings from the survey were analyzed, to identify key theoretical and practical implications for the purpose of informing future industry practices and academic research.

The project was approved by the Swinburne University of Technology's Ethics Committees (Melbourne, Australia) and acknowledged by RMIT University (HCMC, Vietnam) in advance of the survey being distributed. The survey was developed in two language versions, English and Vietnamese, giving participants an option to choose their preferred language.

4 Results

A total of 223 completed survey responses were received, representing participants working across 8 different industry sectors (Fig. 3). 145 responses (65 percent) were male, 78

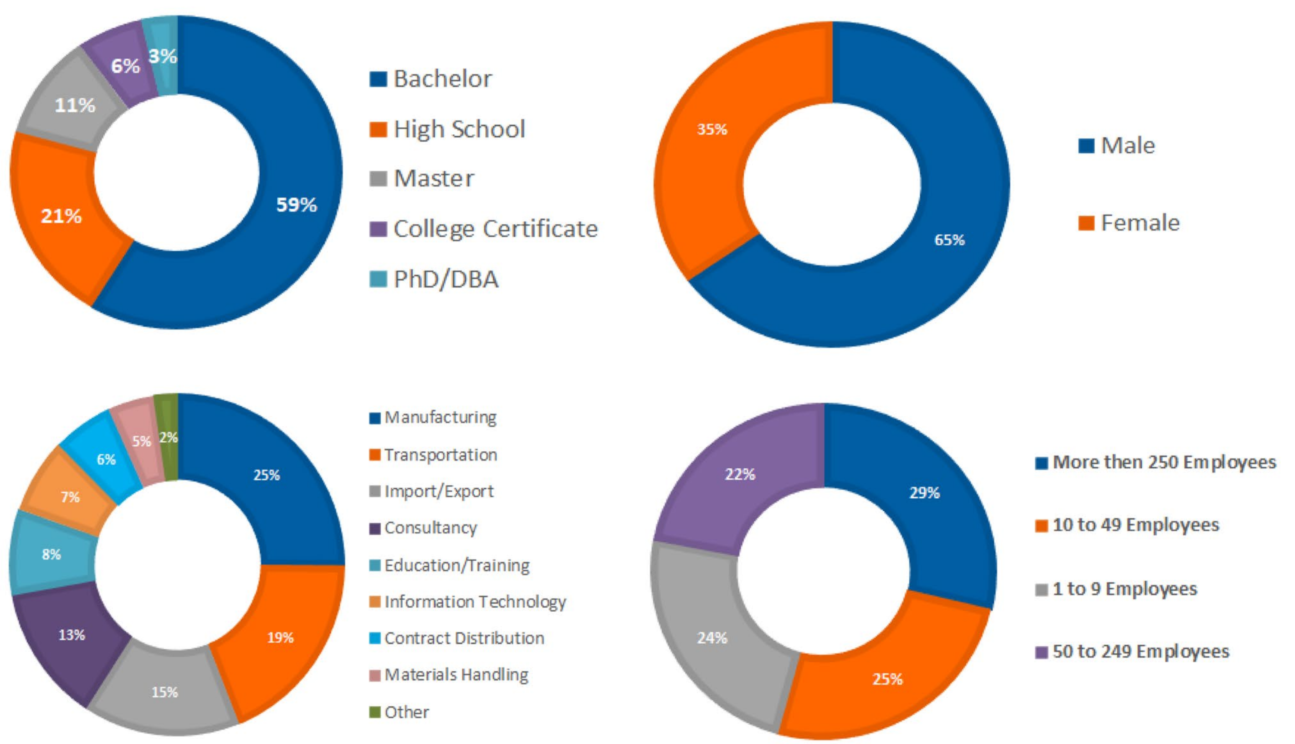


Fig. 3 Participants' demographic information

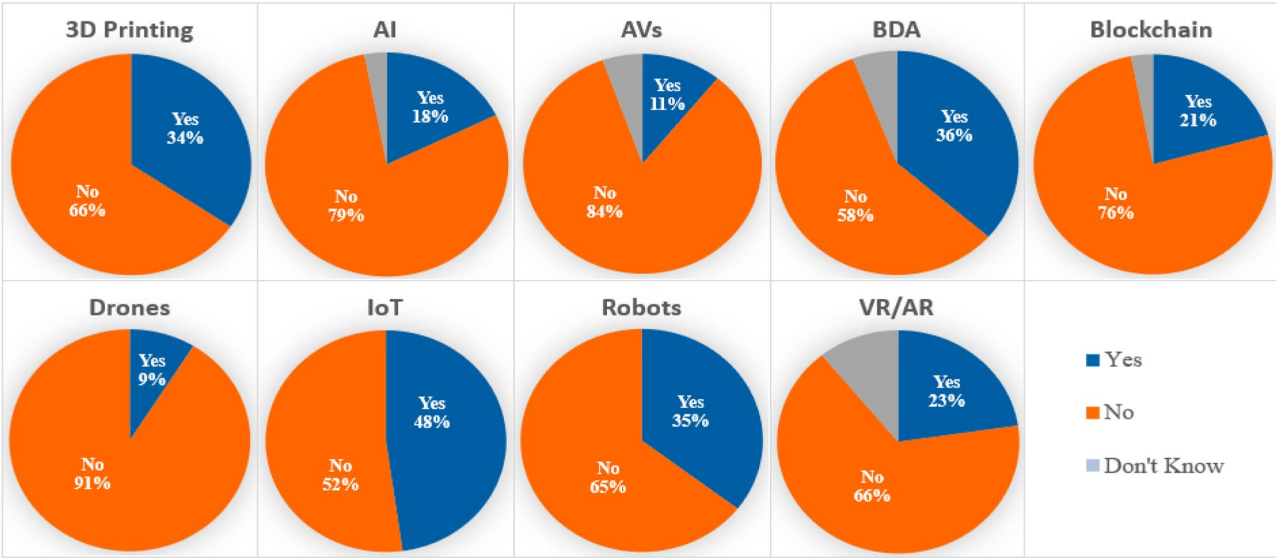


Fig. 4 Current adoption of emerging technology

(35 percent) were female, and the average time taken to complete the survey was 24 min. 85 percent of the participants were under 45 years old and 73 percent had a bachelor's degree or higher qualification.

The participants indicated that there was currently a fairly low level of adoption of I4.0 technologies amongst Vietnamese supply chain firms, with IoT being the most widely adopted (49 percent), followed by BDA (36 percent), and 3DP (34 percent). Drones were the least widely adopted I4.0 technology, with only 9 percent of participants indicating their company currently used them (Fig. 4).

In the following section, results related to each technology are presented in Figs. 5 and 6, and Table 6.

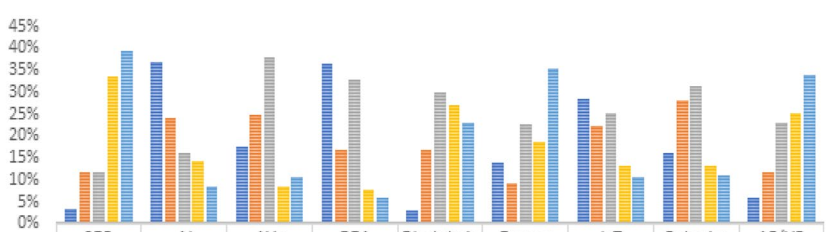
3D Printing (3DP)

It was found that 34 percent of the participants are currently using 3DP technology (see Fig. 6), but only 18 percent of the participants believe this technology will have a significant/great impact on the future of their organization, and only 17 percent expect to see significant investment over the next 10 years in this technology. The areas where 3DP is expected to have the greatest impact are improved product customization and new customer value propositions (CVPs) (RII = 0.850), reduced manufacturing cost (RII = 0.675), and eliminating product ranges (print at home) (0.642). While 33 percent of the participants weren't currently taking any steps to prepare for the application of 3D printing (RII = 0.825), the highest figure was recorded for any of the technologies. 16 percent admitted they were investing in formal upskilling internally (RII = 0.613), with training courses, and research and development.

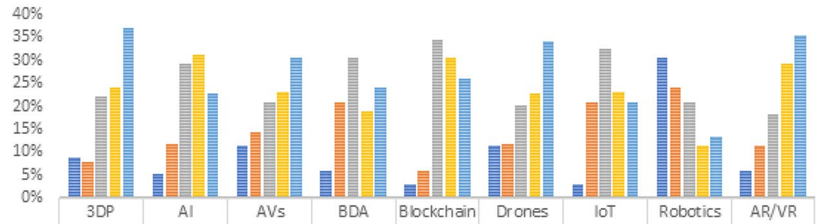
Artificial Intelligence (AI)

18 percent of the respondents confirmed they were currently using AI, but 61 percent predicted that it would have a significant/great impact on their organisation in the future, and 19 percent expected extensive/significant investment by their organization over the coming decade. Improved performance of existing tasks (RII = 0.917) and reduced inefficiencies (RII = 0.708) were the most highly anticipated benefits.

Fig. 5 Predicted impact



	3DP	AI	AVs	BDA	Blockchain	Drones	IoT	Robotics	AR/VR
To a significant extent	3%	37%	18%	36%	3%	14%	29%	16%	6%
To a great extent	12%	24%	25%	17%	17%	9%	22%	28%	12%
To a minor extent	12%	16%	38%	33%	30%	23%	25%	32%	23%
To some extent	33%	14%	8%	8%	27%	19%	13%	13%	25%
Not at all	39%	8%	11%	6%	23%	35%	11%	11%	34%



	3DP	AI	AVs	BDA	Blockchain	Drones	IoT	Robotics	AR/VR
Extensive investment	9%	5%	11%	6%	3%	11%	3%	31%	6%
Significant investment	8%	12%	14%	21%	6%	12%	21%	24%	11%
Some investment	22%	29%	21%	31%	34%	20%	33%	21%	18%
Low level of investment	24%	31%	23%	19%	31%	23%	23%	11%	29%
No investment	37%	23%	31%	24%	26%	34%	21%	13%	35%

Fig. 6 Predicted investment

Investing in upskilling the current internal staff (RII = 0.717) was the key measure being taken to prepare for the emergence of this technology.

Autonomous Vehicles (AVs)

Whilst only 11 percent of participants are already using AVs, 58 percent predict it will have a moderate to a great impact on their organization over the coming years, with the improved performance of existing tasks (RII = 0902) and reduced inefficiencies (RII = 0.797) being the most highly anticipated benefits of this technology. 31 percent of the participating firms predicted there would be no investment in their planning for the emergence of AVs, whilst only 17 percent indicated significant investments in this area over the next 10 years. The greatest impact of AVs is expected to be their ability to eliminate driver wages and lower shipping cost (RII = 0.811), reduce fuel costs (RII = 0.889), and reduce the traffic congestion (RII = 0.856),

Big Data Analytics (BDA)

Table 6 Predicted impacts and preparation measures

Technology	Predicted Impact Areas			Preparation Measures		
3DP	**Rank**	**Factors**	**RII**	**Rank**	**Factors**	**RII**
	1	Greater product customization & new CVPs	0.850	1	No Investment	0.825
	2	Reduced manufacture costs	0.675	2	Investing in Internal upskilling (training & R&D)	0.613
	3	Eliminating product ranges (print at home)	0.642	3	Informal/ad-hoc research & self-education	0.538
	4	Reducing stock & wastage across the SC	0.525	4	Formal research & investigation (consultants)	0.438
	5	Faster manufacturing	0.467	5	Contracting out development & implementation	0.388
	6	Reducing transportation and storage costs	0.458	6	New hires (hiring experts)	0.313
	7	Spare parts availability	0.383	7	Establishing partnerships with specialist firms	0.363
	8	Better supply chain response times	0.350	8	Negligible investment	0.363
AI	1	Improve performance of existing tasks	0.917	1	Investing in upskilling internally (training & R&D)	0.717
	2	Reduce inefficiencies	0.708	2	No Investment	0.583
	3	Replace manual jobs	0.592	3	Informal/ad-hoc research & self-education	0.483
	4	Create new jobs in my sector	0.475	4	New hires (hiring experts)	0.400
	5	Increase customer sales	0.458	5	Formal research & investigation (consultants)	0.400
	6	Real-time fraud and risk management	0.370	6	Negligible investment	0.367
	7	Improved inventory placement	0.350	7	Establishing partnerships with specialist firms	0.267
				8	Contracting out development & implementation	0.267

Table 6 (continued)

Technology	Predicted Impact Areas			Preparation Measures		
AVs	1	Improve performance of existing tasks	0.902	1	Eliminate driver wages & lower shipping costs	0.811
	2	Reduce inefficiencies	0.797	2	Reduce fuel costs	0.889
	3	Replace manual jobs	0.682	3	Reduce traffic congestion	0.856
	4	Create new jobs in my sector	0.467	4	Improve worker productivity (work while commuting)	0.689
	5	Increase customer sales	0.451	5	Improve pedestrian safety	0.533
	6	Real-time fraud and risk management	0.397	6	Improve driver safety & reduce liability	0.444
	7	Improved inventory placement	0.349	7	Improve customer service (delivery & time options)	0.378
				8	Reduce pollution (truck platooning/electric vehicles)	0.348
BDA	1	Predictive analytics/causal forecasting/lead indicator analysis	0.867	1	Establishing partnerships with specialist firms	0.929
	2	Recognition of new sales & market opportunities	0.767	2	New hires (hiring experts)	0.835
	3	New business insights	0.592	3	Investing in upskilling internally (training & R&D)	0.788
	4	Client base segmentation	0.542	4	Informal/ad-hoc research & self-education	0.518
	5	New lead generation	0.517	5	Contracting out development & implementation	0.441
	6	Better targeted marketing	0.450	6	No Investment	0.429
	7	Create new business opportunities/competitive advantages	0.433	7	Formal research & investigation (consultants)	0.341
	8	Process optimization/cost reduction	0.358	8	Negligible investment	0.341
Blockchain	1	Improve administration, record keeping reliability & accuracy	0.858	1	No Investment	0.845
	2	Supply chain transparency	0.750	2	Investing in upskilling internally (training & R&D)	0.704
	3	Supply chain contract management	0.733	3	New hires (hiring experts)	0.564
	4	Enable new apps and channels	0.583	4	Formal research & investigation (consultants)	0.564
	5	Create new business opportunities/competitive advantages (proof of product providence)	0.433	5	Informal/ad-hoc research & self-education	0.418
	6	Improve supplier & supply chain collaboration	0.425	6	Establishing partnerships with specialist firms	0.364
	7	Serve as a platform to manage other technologies (IoT, big data, etc.)	0.367	7	Contracting out development & implementation	0.318
	8	Enable faster & cheaper fundraising as an alternative to debt/equity (ICOs)	0.325	8	Negligible investment	0.000
Drones	1	B2C deliveries (direct to customer/last mile)	0.938	1	No Investment	0.975
	2	Cost reduction	0.801	2	New hires (hiring experts)	0.775
	3	Shorter lead-times	0.675	3	Investing in upskilling internally (training & R&D)	0.763
	4	B2B deliveries (across the supply chain)	0.644	4	Contracting out development & implementation	0.563
	5	New CVPs and competitive advantage	0.481	5	Formal research & investigation (consultants)	0.500

Table 6 (continued)

Technology	Predicted Impact Areas			Preparation Measures		
	6	Improve exploratory capability	0.431	6	Establishing partnerships with specialist firms	0.450
	7	Management roles (agriculture, warehouse & store management)	0.425	7	Informal/ad-hoc research & self-education	0.351
				8	Negligible investment	0.000
IoT	1	Supply Chain efficiencies (warehouse/transport admin & processing)	0.875	1	No Investment	0.886
	2	Real-time tracking/traceability	0.750	2	Internal investment in upskilling (training/R&D)	0.771
	3	Predictive maintenance (decrease downtime/lower costs)	0.708	3	Establishing partnerships with specialist firms	0.700
	4	Environment monitoring (manufacturing/storage conditions)	0.683	4	Formal research & investigation (consultants)	0.543
	5	More accurate forecasting and better production optimization	0.550	5	New hires (hiring experts)	0.543
	6	Improved inventory monitoring/reduction in stock-outs	0.483	6	Informal/ad-hoc research & self-education	0.443
	7	Personalized marketing	0.475	7	Negligible investment	0.171
	8	More accurate carbon monitoring	0.425	8	Contract development/implementation	0.143
Advanced Robotics	1	Automation of last-mile deliveries	0.917	1	Establishing partnerships with specialist firms	0.817
	2	Manufacturing	0.842	2	Internal investing in upskilling (training/R&D)	0.767
	3	Lifting heavy loads	0.658	3	Formal research & investigation (consultants)	0.667
	4	Working in hazardous industries/environments	0.517	4	New hires (hiring experts)	0.650
	5	Service Industry	0.458	5	Contracting development/implementation	0.650
	6	Automation of predictable/repetitive tasks	0.358	6	No investment	0.583
	7	Fewer worker injuries	0.350	7	Informal/ad-hoc research & self-education	0.421
				8	Negligible investment	0.398
AR/VR	1	New social media channels	0.842	1	No Investment	0.829
	2	Virtual work environment	0.792	2	Internal investing in upskilling (training/R&D)	0.771
	3	Product visualization / design	0.717	3	New hires (hiring experts)	0.686
	4	New marketing channel to drive sales	0.592	4	Formal research & investigation (consultants)	0.500
	5	Education & Training	0.433	5	Negligible investment	0.414
	6	Virtual brochure/showrooms	0.425	6	Internal investing in upskilling (training/R&D)	0.397
	7	New CVPs/competitive advantage	0.395	7	Establishing partnerships with specialist firms	0.371
	8	Improved order picking/inventory management	0.350	8	Contracting out development & implementation	0.307

The findings indicated that 36 percent of participants were currently using BDA, which is the second-highest adoption rate of all the I4.0 technologies in this study. 86 percent of the responses highlighted a moderate-to-great impact expectation for BDA, in the areas of predictive analysis, casual forecasting or lead indicator analysis (RII = 0.867), and the recognition of new sales and market opportunities (RI = 0.767). 25 percent of the respondents predict a significant level of financial investment from their organization in this area. Firms have already taken a range of preparatory measures to leverage BDA, such as a partnering with specialist firms (RII = 0.929), and hiring new experts (0.835).

Blockchain

21 percent of the participating companies have currently implemented Blockchain and 20 percent expect it to have a significant impact on their organization. However, little investment was expected by most participants (RII = 0.845), with only 9 percent indicating extensive/significant spending on Blockchain by the firms. The areas where Blockchain is predicted to have the most significant impact over the next 10 years are in improving administration and record-keeping accuracy (RII = 0.858), supply chain transparency (RII = 0.750), and contract management (RII = 0.733).

Drones

The results indicate that the adoption rate of drones is the lowest of all I4.0 digital technologies in this study, with only 9 percent of the participants reporting they currently use this technology, and only 23 percent predicted a significant to a great impact on their organization. The most significant impact areas for drones are predicted to be in last-mile delivery (RII = 0.938) and cost reduction (0.801). Whilst no investment was expected by most participants (RII = 0.975), there was evidence of preparatory measures, and investment in hiring experts (RII = 0.775).

Internet of Things (IoT)

IoT was discovered to be the most widely adopted of all nine I4.0 technologies, with 48 percent of the participants indicating they had already implemented IoT, and 51 percent predicting it will have a significant-to-great impact on their organization. Supply chain efficiency (RII = 0.875), real-time tracking and traceability (RII = 0.750) and predictive maintenance (RII = 0.708), are the areas where it is expected to have the most impact. Whilst internal investment for upskilling (RII = 0.771) and establishing partnerships with specialist firms (RII = 0.700) were most popular preparatory measures being taken by the firms, many firms were identified as still not expecting any investment at all (RII = 0.886).

Advanced Robotics

Thirty-five percent of the responses illustrate the use of some sort of advanced robotics today, making it the third-highest adopted I4.0 technology in Vietnam. 55 percent of the participants indicated a significant-to-extensive level of investment by the firms on robotics, where 44 percent forecasted a great/significant impact on their organization. The greatest impact from robotics was predicted to be in the automation of last-mile delivery (RII = 0.917) and manufacturing (RII = 0.842). The firms preparing to adopt this technology are establishing partnerships with specialist firms (RII = 0.817) and investing in upskilling their existing workforce (RII = 0.767).

Virtual Reality (VR) / Augmented Reality (AR)

Twenty-three percent of the participants reported already having adopted AR/VR, 18 percent predicted it would have a significant and great impact on their organisation, and 17 percent said they were already investing in upskilling staff (RII = 0.771). The key impact of this technology is expected to be in new social media channels (RII = 0.842), creating virtual work environments (RII = 0.717), and in product visualization and design (0.717).

4.1 Most significant overall impact

Participants were asked to identify what they believed to be the most impactful technologies overall, by awarding '9' to the most impactful technology and '1' to the least impactful. From the heat map this generated, it is noticeably visible that the technologies expected to have the most significant impact on Vietnamese supply chain most are Drones, BDA, and IoT (Fig. 7). In contrast, despite the low current implementation of Drones more participants awarded this technology with a '9' score than any others, indicating they expect they could have the highest impact overall on Vietnamese supply chains.

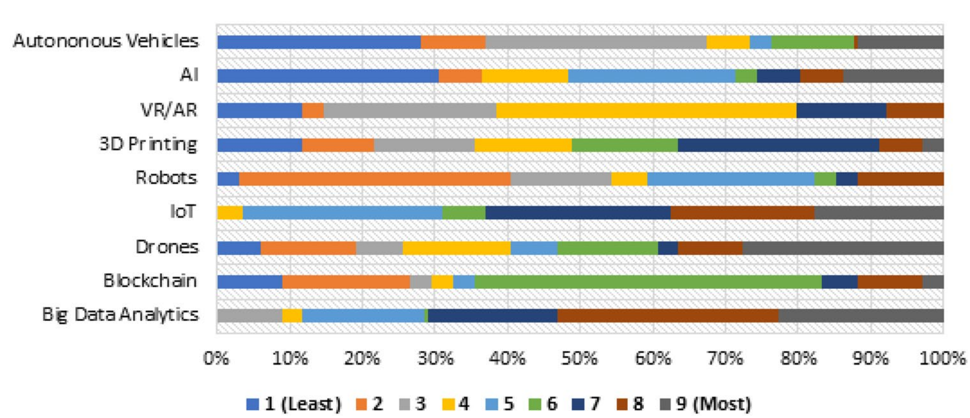


Fig. 7 Most significant overall impact of emerging technologies

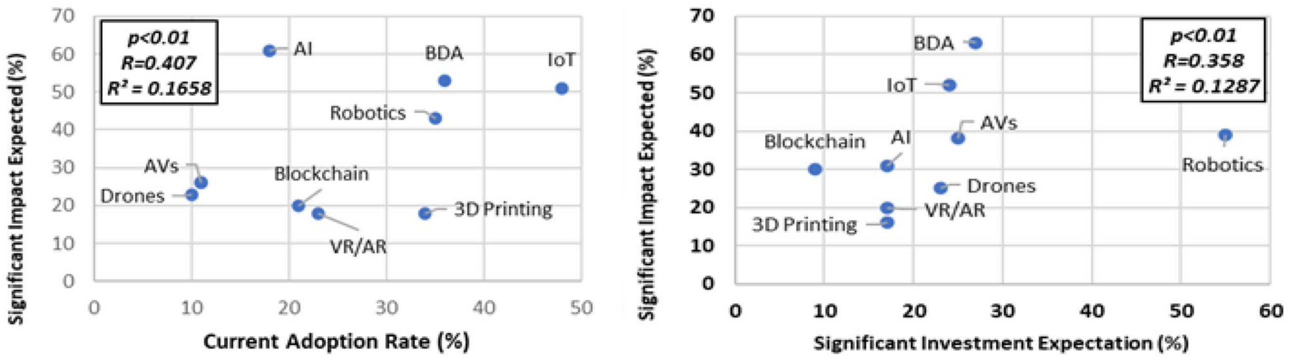


Fig. 8 Current adoption and investment expectation vs. impact expected

4.2 Current adoption and investment expectation vs. future expected impact

To examine the relationships between the current adoption of emerging technologies and future impact ($p<0.01$, $R=0.407$, $R^2=0.1658$), and investment expectation and expected impact ($p<0.01$, $R=0.358$, $R^2=0.1287$), standard correlations were performed. The positive significant correlations demonstrate that the future impact becomes progressively higher depending on the current adoption level and investment expectations (Fig. 8).

4.3 Concerns

Whilst recognising many benefits of the nine emerging digital technologies in supply chains, the participants also voiced several concerns, including security and hacking (44 percent), and a loss of jobs in their sector (27 percent) (Fig. 9). As supply chains become increasingly digital, concerns related to data security, cybersecurity and cybercrime, are understandable and inevitable.

5 Discussion

The supply chain practitioners participating in this study indicated IoT was currently the most widely adopted I4.0 digital technology in Vietnam, with an adoption rate of 48 per cent, and that BDA, IoT, and Drones were predicted to have the most significant impact on supply chain sustainability in the long term.

IoT's ability to support greater supply chain visibility and information sharing has been found to enhance sustainable performance (de Vass et al. 2020), and minimize inventory levels (Jamwal et al. 2021; Malek and Desai 2019; Moktadir et al. 2018). Abdel-Basset et al. (2018) have previously discussed links between IoT, traceability and waste control, whilst Hopkins and Hawking (2018) described a range of sustainability benefits

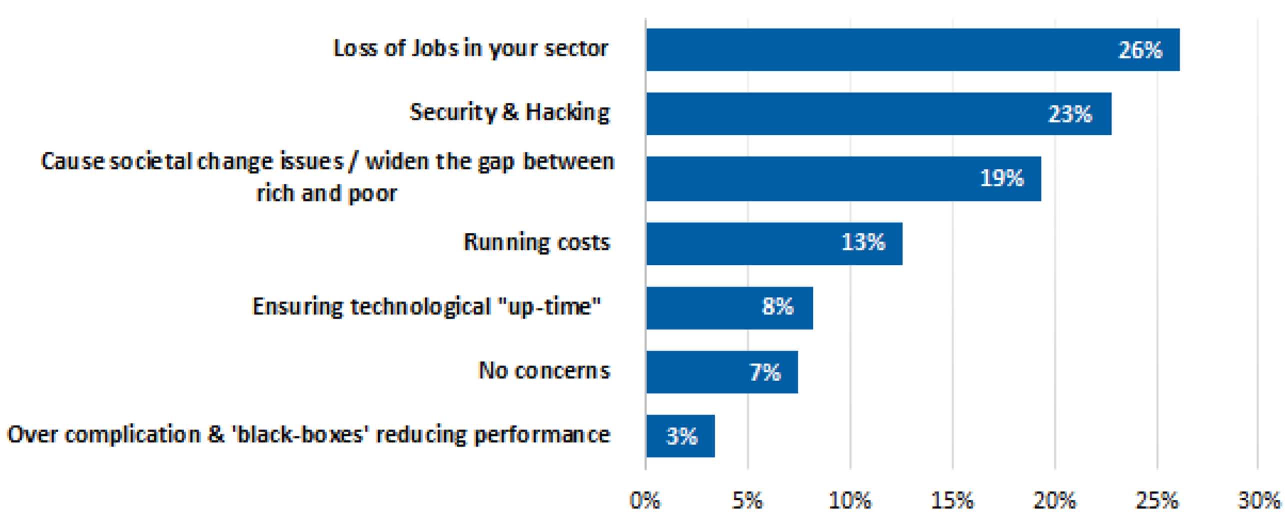


Fig. 9 Concerns regarding emerging technologies

arising from the adoption of IoT-enabled truck telematics, including a reduction in accidents and injuries, and a reduction in GHG emissions, due to the improved driving behaviours. According to Hong et al. (2019), the adoption of IoT technologies also enables firms to compete globally and reach international standards.

BDA is believed to influence sustainable performance, due to its capacity for monitoring the internal processes which constitute sustainable capability (Singh and El-Kassar 2019), and a positive relationship has been identified between BDA capability and organizational human capital, also leading to sustainable supply chain outcomes (Bag et al. 2020). Moreover, Mani et al. (2017) found that BDA can also be used to predict and mitigate a range of supply chain risks, including workforce safety, fuel consumption monitoring, workforce health, security, vehicle maintenance, speeding and traffic violations.

Drones are commonly believed to be capable of improving the sustainability of business-to-customer (B2C) deliveries, whilst reducing traffic congestion and pollution (Rao et al. 2016), they promote cleaner agricultural production and CE strategies (Mahroof et al. 2021), and mitigate many transport challenges faced by humanitarian supply chains (Azmat and Kummer 2020).

When comparing current adoption with expected impact, and expectation in investment, and expected impacts, linear relationships were found and evidenced between both (Fig. 8). However, the relationship between expected impact and forecast investment was quite different. Whilst 53 percent of participants predicted that BDA would have a significant impact on their organization over the next 10 years, only 27 percent expected their firms to make a significant investment in this technology. Similarly, while 61 percent of respondents predicted a significant impact for IoT, only 24 percent expected appropriate investment. These large impact/investment gaps could offer the most significant future opportunities for competitive advantage and sustainability gains.

The technologies attracting the highest demand for new talent were BDA (RII = 0.825), Drones (RII = 0.775), and AR/VR (RII = 0.686), underlining the need for the introduction of new supply chain skills in emerging economies, and aligned with Columbus (2015) and Radovilsky et al. (2018), who identified BDA as a key future employment area.

Less has been written about the relationship between AR/VR and sustainability outcomes, but this I4.0 technology has been found to reduce travel requirements for recruitment, development, training and personnel evaluation purposes (Zhao et al. 2019), leading to energy and transport savings. It also enables realistic simulations of products or infrastructure to be created, for testing and piloting in advance of the development of physical models, leading to a reduction in wasted resources (Berg and Vance 2017; Jamei et al. 2017).

Internal investment in upskilling was found to be highest for AI (RII = 0.717), Advanced Robotics (RII = 0.767), IoT (RII = 0.771), and Blockchain (RII = 0.704). Informal self-education and upskilling internally were the most common preparatory measures being taken for I4.0 adoption, presenting opportunities for universities/colleges/training institutions, students, and graduates.

Similar to BDA, AI uses predictive analytics to model future scenarios, which can be used to improve waste management (Ramchandran et al. 2017), enhance energy efficiency (Dauvergne 2020), mitigate risk (Baryannis et al. 2019), and assist society in the reduction of energy, water and land use (Nishant et al. 2020). AI can help managers identify new trends in employee data, for customized training and development opportunities (Lengnick-Hall et al. 2018), whilst AI-powered location awareness systems can be utilised to detect human or machine actions which may pose a safety risk (Ghobakhloo 2020; Kamble et al. 2018).

The use of robotics has also been linked to reductions in energy usage and GHG emissions (Lee et al. 2015a, b), as well as more efficient use of raw materials (Cousineau and Miura 1998), an ability to conduct large-scale environmental monitoring (Dunbabin and Marques 2012), and improvements in safety which result in fewer injuries and fatalities (Castro-Lacouture 2009).

The transparency offered by Blockchain encourages extended producer responsibility, whereby manufacturers are required to have greater accountability for their products after they reach the end of their lifecycle and require collection for recycling or correct disposal (Esmaeilian et al. 2020). It can help minimize inventory waste, by reducing the bullwhip effect, and improve food safety and traceability (Esmaeilian et al. 2020; Tian 2016). In addition to this, Saberi et al. (2019, p. 2131) encourage investigations into 'the environmental and social/humanity dimension of sustainability', for future studies into blockchain-enabled supply chain effectiveness.

Examining each sector (Table 7), BDA and IoT were found to be the most commonly adopted technologies within Consulting, Manufacturing, Education, Material Handling, Import/Export, IT, Contract Distribution. A similar result emerged for expected impact, with BDA and IoT expected to have the greatest impact in all sectors apart from Contact Distribution, aligning with the findings of Bai et al. (2020).

BDA and IoT also attracted the greatest expected spending across all sectors, apart from Materials handling and Contract Distribution, where Robotics spending was more highly anticipated. Of all technologies examined, AR/VR, Blockchain, and AVs attracted the least investment and were predicted to have the lowest impact on Vietnamese supply chains over the next decade. The lack of investment for Blockchain was also identified by Kouhizadeh et al. (2021).

Whilst they weren't predicted to have the biggest impact on Vietnamese supply chains, AVs are expected to use less fuel and emit less GHG than current vehicles, due to

Table 7 Adoption rates, predicted impact and spend areas, by industry

Sector	Highest Current Adoption	Greatest Expected Impact	Greatest Expected Spend
Consulting	*BDA/IoT (40%)*	*IoT (51%)*	*BDA (59%)*
Manufacturing	*BDA/Robotics (71%)*	*IoT/Robotics (55%)*	*IoT (64%)*
Education/Training	*BDA/IoT (61%)*	*BDA (58%)*	*BDA/IoT (54%)*
Materials Handling	*IoT/Robotics (69%)*	*BDA/IoT (57%)*	*Robotics (79%)*
Import/Export	*BDA (63%)*	*BDA (61%)*	*IoT (68%)*
IT	*BDA/IoT (89%)*	*BDA/IoT (73%)*	*BDA (82%)*
Contract Distribution	*BDA (68%)*	*AI (54%)*	*Robotics (78%)*
Others	*3DP (52%)*	*BDA/IoT (59%)*	*BDA/3DP (58%)*

improved routing, eco-driving and the reduced distances possible between vehicles (Khakurel et al. 2018).

The empirical results and implications of this paper shed light on the application of I4.0 digital technologies in emerging economies and suggests new approaches to the adoption of technologies and sustainable developments. The results have also revealed a disjoint in the investment framework on I4.0 compared with the potential impact of the technologies.

I4.0 digital technologies can assist in tackling many sustainability challenges when combined with human ecology, psychology, and ethical attributes, which are essential to the success of sustainable development. CE as a new business mindset can support firms and society to move towards sustainable development.

Bag et al. (2021a) recently discussed the role I4.0 technologies can play in supporting CE-based models, in helping to keep resources within the system by enabling 10 R methodologies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover). Similarly, Kumar et al. (2021) have identified links between increased digitalization and resource circularity, and recommend a need for the principles of I4.0 and CE to be integrated into technology planning.

The emergence of I4.0 digital technologies makes CE more feasible and, for many emerging economies, an increase in I4.0 technology adoption can potentially support their overarching sustainability goals. In Vietnam, this would align with the country's aspiration of achieving the Voluntary National Review (VNR) under the 17 SDGs covered in the UN's plan (UNSD 2018). If I4.0 technologies are widely adopted in Vietnam, there will be an urgent need to upskill the workforce (World Bank 2021).

5.1 Theoretical implications

The adoption of I4.0 digital technologies has been widely studied in developed countries (Kumar and Siddharthan 2013), but the prospective impact of the I4.0 technologies in emerging economies is lacking (Dalenogare et al. 2018), with less known about the current landscape in those regions (Jabbour et al. 2020). In line with recent calls for a more detailed investigation into appropriate technologies (Bai et al. 2020; Frederico et al. 2020), the resulting framework extends current knowledge within the domain of I4.0 in sustainable SCM theory.

This exploratory study contributes a novel insight into each of the technologies from a lens of supply chain sustainability, offering new perspectives into emerging economies, and extending the existing knowledge of digitalization. The adapted framework synthesizes the fragmented body of literature and provides comprehensible insights into the current adoption of I4.0 technologies. The application of I4.0 technologies is reaching an exciting era and has great potential to support digitalization that results in sustainability benefits. By addressing the research questions, this investigation has denoted BDA and IoT as the most widely adopted I4.0 technologies in this emerging economy and discovered that they both offer potential improvements in supply chain transparency, forecasting accuracy, operational resilience and CP processes.

This study contributes to the existing body of knowledge, by extending the understanding of emerging I4.0 technologies, through the lens of SCM. In particular, it reveals a significant gap between "*expected impact*" of emerging technologies and "*forecasted investment*". Where the previous studies have focused more on adoption barriers and challenges, this study has explored in detail the relationship between "*current adoption*" and "*future impact*", in addition to "*investment expectation*" and "*expected impact*".

The emergent framework expands upon previous understanding and, in essence, signposts both practical and theoretical relationships between these values. Notwithstanding, "*investment*" and "*impact*" are revealed to have inverse directionality, where impact should be the main focus, and investment flows and follows accordingly. This challenges the current ideology and approach undertaken in many sustainable supply chains.

Concurrently, the framework has continued to affirm the ideology that the appropriate adoption of emerging technologies is vital to attain future supply chain sustainability goals, and remains consistent for emerging economies. This is not only still consistent, but also holds true in emerging economies, such as Vietnam.

The adaptability of the technology is also evident from the study, furthering situational understanding of not only its applicability but its successful usage in different industries. This suggests an additional contextual layer and variable that needs consideration when adopting emerging technologies. As a result, adoption could be influenced by the industry in focus and thereby suggests a myriad of opportunities for future academic discourse.

5.2 Implications for practice

Findings indicate most of the emerging technologies are still at the early stages of adoption in Vietnam, and impact predictions and investment forecasts vary across the different sectors, meaning managers need to identify the most appropriate technologies for their individual needs.

Impact predictions and investment forecasts were misaligned, which may raise concern that spending plans are not appropriately focussed, or highlight possible opportunities. Importantly, the key driver for selecting technologies is their impact potential, where investment should yield better results. This supports a targeted approach to I4.0 investment, where firms consider what they need and the sustainable outcomes they desire, rather than simply following trends.

Increased awareness of CE amongst practitioners will result in better supply chain sustainability outcomes, but implementing this concept takes time to gather the necessary information and resources and redesign configurations accordingly (Bag et al. 2021a, b). Therefore, managers need to focus on education and integrating CE thinking into their long-term planning.

6 Conclusions, limitations, and future direction

Vietnam is a region that has significant potential for growth as a global centre for manufacturing, as supply chains look to reduce their over-reliance on China, in the aftermath of COVID-19. If manufacturing in Vietnam grows to the expected extent, and the adoption of appropriate I4.0 digital technologies is a component of that growth, there will be significant scope for improved supply chain sustainability, and support for CP and CE concepts.

This research has highlighted an overall low level of adoption of I4.0 digital technologies amongst Vietnamese supply chain firms. However, when designing new facilities and supply chains, there is often a greater opportunity for the inclusion of sustainability, CP, and CE practices than interrupting and retrofitting new features into established networks and infrastructure.

Therefore, sustainability considerations could form a significant component of any growth plan, with the appropriate digital technology requirements included in the blueprint. Planning for training and other preparatory measures will also be required in order to meet the rising demand for new skills in the industry, needed to operate, monitor, manage, maintain and leverage the maximum benefit from the deployment of these new digital technologies.

This empirical study has generated a range of interesting new insights into the current supply chain landscape in Vietnam, and discussed a range of supply chain sustainability improvements, possible through I4.0 digital technologies. The developed framework remedies a gap in current research on digital supply chains, by examining the existing adoption levels of digital technologies, and their potential for driving positive sustainability outcomes. The research also extends the current theoretical base by considering I4.0 digital technology adoption from the lens of an emerging economy and its possible implications for similar countries.

These findings have significant implications for practitioners and scholars alike, as the configuration of global supply chains starts to shift in the post-COVID-19 era, and academics seek to follow new emerging trends. The digital technologies featured in this investigation will play a key role in the COVID-19 recovery, as supply chains look to increase their resilience to future shocks through the adoption of more digital and automation technologies, and the authors hope this new data will provide timely input for policymakers and practitioners alike, as they design their sustainability roadmaps and navigate the challenging years which lie ahead.

The current study has a number of limitations that provide opportunities for future research directions. As the sample is concentrated on the two largest cities in Vietnam, Hanoi and Ho Chi Minh, further investigation is required to provide more comprehensive nationwide insights. Even though the findings of the study are robust, the results presented in this study are limited to industry respondents concentrated around these two cities, and as such there are caveats to the wider applicability of the framework.

Online surveys also have their limitations, as questions may be interpreted differently by different participants, and respondents may not feel comfortable providing answers which present them or their organisation in a negative light. Their asynchronous nature doesn't facilitate clarification, or the exploration of different avenues of investigation, that can arise during interviews or focus groups.

To overcome this, the next stage of this research project will be a series of four focus groups, conducted online with groups of 8–10 Vietnamese supply chain professionals. The purpose of these focus groups will be to explore the themes emerging from this paper in greater detail, and

Table 8 List of Abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
3DP	Three-Dimensional Printing	GDP	Gross Domestic Product
AI	Artificial Intelligence	GHG	Greenhouse Gas
AM	Additive Manufacturing	HCI	Human Capital Index
AR	Augmented Reality	I4.0	Industry 4.0
ASEAN	Association of Southeast Asian Nations	IoT	Internet of Things
AV	Autonomous Vehicles	RFID	Radio Frequency Identification
BDA	Big Data Analytics	SCM	Supply Chain Management
CE	Circular Economy	SDGs	Sustainable Development Goals
CO2	Carbon Dioxide	UN	United Nation
COVID-19	Coronavirus Disease 2019	UNEP	United Nations Environment Programme
CP	Cleaner Production	VNR	Voluntary National Review
FDI	Foreign Direct Investment	VR	Virtual Reality

collect qualitative data, to gain a more in-depth understanding of the role digital technologies play as enablers of supply chain sustainability in Vietnam. Combining quantitative and qualitative research methods like this, improves the overall quality of the research, and supports a deeper understanding of the focus area.

Moreover, there are also opportunities to extend this research into other emerging economies, such as Thailand or Indonesia, which are expected to attract similar growth as a result of manufacturing being moved away from China. Future research, especially investigations which focus on emerging economies, will need to consider the infrastructure and availability of appropriate workforces to successfully embed I4.0.

Inevitably, there will be other factors which also impact the success of I4.0 in improving supply chain sustainability, and the authors recommend the need for further research to understand those factors in greater detail (Table 8).

Acknowledgements The authors would like to thank Dr. Seng Kiat Kok for his encouragement and support throughout this research.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Mohammadreza Akbari and John Hopkins. The first and final draft of the manuscript was written by both authors.

Funding Research was not funded by any organisation.

Availability of data and materials The questionnaire was designed to be anonymous, and therefore the data captured cannot be traced to any individual. No personal information about any participant was provided to researchers, or any other individual or organisation.

Code availability Custom code.

Declarations

Ethics approval The research protocols used in this study were approved by the Ethics Committees of the Swinburne University of Technology [SHR Project 2017/363], and were acknowledged by RMIT University (Australia & Vietnam).

Conflict of interest The authors declare they have no conflict of interests.

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