



Role of project management on Sustainable Supply Chain development through Industry 4.0 technologies and Circular Economy during the COVID-19 pandemic: A multiple case study of Thai metals industry

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Received: 29 June 2021 / Revised: 2 May 2022 / Accepted: 28 May 2022 / Published online: 28 June 2022
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Abstract

The COVID-19 pandemic has widely disrupted manufacturing industries. This research focuses on how project management, Industry 4.0 technologies, and the Circular Economy contribute to Sustainable Supply Chain development during the pandemic. A multiple case study focusing on three companies in the metals industry, covering small-, medium-, and large-size companies from Thailand, is adopted to investigate the impact of the pandemic on companies using the dimensions of demand, production, and distribution disruptions. The result shows that project management supports Industry 4.0 technologies and Circular Economy adoption. Moreover, the COVID-19 pandemic also expedites Industry 4.0 technologies adoption. Product customization is one of the key focuses of the companies to differentiate from the competitors and create long-term competitive advantages. Industry 4.0 technologies and the Circular Economy have a positive influence on Sustainable Supply Chain development.

Keywords Project management · Sustainable Supply Chain · Industry 4.0 technologies · Circular Economy · Metals industry

1 Introduction

The appearance of the 2019 coronavirus (COVID-19) that started in December 2019 has become a serious global epidemic (Lai et al. 2020). The pandemic impacts consumption behaviors and production activities, requiring a more sustainable way of consumption and production (Mont et al. 2021). United Nations Industrial Development Organization (2020) reports that demand reduction is one of the main impacts of COVID-19 on the Thai industrial sector, and low-tech firms have significantly suffered from the pandemic. In 2020, the Thai economy was estimated to contract by 5% as a result of the COVID-19 pandemic (World Bank Group 2020). During the pandemic, the adoption of Industry 4.0 technologies, shared responsibility, and supply chain collaboration promotes sustainable development by helping firms control risks and evade negative impacts (Sharma et al. 2020). Digital resources have been identified as facilitators for product development under limited resource availability (Caballero-Morales 2021). Industry 4.0 technologies support manufacturing companies to enable closed-loop

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material flow, resulting in improved business sustainability and competitiveness (Enyoghasi and Badurdeen 2021).

Recent studies have already investigated various operation management concepts during the COVID-19 pandemic to promote understanding and seek for solutions to the pandemic's impacts affecting the operations of manufacturing companies. The positive impacts of these concepts have been presented by the previous studies. Muhammad et al. (2022) notice the positive impacts of Lean and Six Sigma on a firm's performance during the pandemic. The impact evaluation in terms of footprinting can lead to effective environmental impact reduction and a significant positive financial performance (Dhiyf et al. 2021). Firm capability and business contingency can be the major parts of supply chain strategy that leads to supply chain sustainability (Chatterjee and Chaudhuri 2021). Digital technologies help the supply chain to become more resilient to future disruptions (Hald and Coslugeanu 2021). The common benefits of these studies provide insights for manufacturing firms and industrialists in selecting appropriate operation management tools and concepts to retain and improve performances during the pandemic. This study seeks to further expand the current research boundary by focusing on the multiple drivers for Sustainable Supply Chain (SSC) development which are project management, Industry 4.0, and Circular Economy (CE). Our study chooses to investigate the SSC development of three selected Thai metals manufacturing companies with different sizes to present interesting perspectives of the developing country where available resources and readiness to address disruptions recovery are quite limited.

From the theoretical point of view, the Resource-Based View (RBV) offers perspectives on the understanding of how technological resources, Industry 4.0 technologies, develop competitive advantages of the companies. Moreover, contingency theory is employed in this study to support the framework development as presented in Sect. 3. The RBV is vital for companies to identify resources valuable for the implementation of Industry 4.0 technologies. The significance of Industry 4.0 technologies in promoting sustainable production and CE capabilities is identified from the RBV perspective by a recent study (Bag et al. 2021d). The RBV highlights the importance of pushing the technological capability of companies to remain competitive (Wernerfelt 1984). The resources and capability can contribute to higher firm performance (Ferreira and Fernandes 2017) and organizational sustainability (Chauhan et al. 2021). Therefore, perspectives from the RBV serve as the input to understand the necessary resources required to promote competitive advantage.

Project management is an essential element when firms adopt technology, and factors such as leadership and communication are important for embedding sustainability

with project management (Wang et al. 2017). Additionally, project management has been identified as one of the key resources for the Industry 4.0 transition (Bag et al. 2021d). Sánchez (2015) highlights the importance of integrating sustainability into project management, supporting a company to achieve business strategy and stakeholder requirements. The embedment of sustainability into project management, through three main principles: environment, economy, and society, can enhance a company's competitive advantages and sustainable development (Chofreh et al. 2019). Project management can support the process of integrating sustainability into the business (Marcelino-Sádaba et al. 2015). Keeyes and Huemann (2017) highlight that organizations can find ways for their stakeholders to achieve sustainable development benefits together through practices such as adaptive learning, goal-driven process, continuous shaping process, and shared vision. They also point out that the consideration of benefit expectations and risk concerns of a broad group of stakeholders is required when creating long-term benefits via projects.

Previous studies have already identified the benefits of Industry 4.0 technologies and CE in developing sustainable production (Bag et al. 2021d) and improving sustainability performance (Gupta et al. 2021). Industry 4.0 technologies and the CE can support the improvement of the company's business model (Massaro et al. 2021). The adoption of Industry 4.0 technologies enables real-time information sharing within the supply chain network, supporting stakeholders with highly responsive decision-making (Manavalan and Jayakrishna 2019). Consequently, the common organizational goals such as increased productivity and desirable sustainable development characteristics including supply chain resilience and agile business process that help companies to meet dynamic demand can be realized (Sharma et al. 2020). At the supply chain level, Industry 4.0 technologies also serve as a key determinant for SSC development (Mastos et al. 2020).

Industry 4.0 technologies and the CE are supporting tools for each other when used for sustainable development. The benefits of Industry 4.0 technologies are as previously stated. For the CE, it has been recognized as the main driver to promote resilience and sustainability (Wuyts et al. 2020). The use of CE together with Industry 4.0 technologies can ensure the sustainability of a company's operations (Kumar et al. 2021). Digital supply chain networks have been known to positively impact sustainable performance, such as cost and waste reduction, of manufacturing companies (Sharma et al. 2022). Within the wider context of supply chain management, Industry 4.0 technologies can support the use of CE principles in improving the sustainability performance of reverse supply chains (Dev et al. 2020). Therefore, understanding how companies manage and utilize Industry 4.0

technologies and CE practices to create an SSC can help them promote long-term competitive advantages. However, the study that bridges these concepts and takes into consideration the impact of the pandemic is still limited, and this study aims to expand the knowledge in this area.

In order to fill the research gap, our study focuses on COVID-19 disruption and investigates the implementation of project management, Industry 4.0 technologies, and CE practices to develop an SSC as possible sustainable solutions to the disruption. This study focuses on the metals industry in Thailand. The following Research Objectives (ROs) are proposed:

RO1 To explore SSC development in the Thai metals industry during the COVID-19 pandemic.

RO2 To investigate project management, Industry 4.0 technologies, and the CE as the enablers of SSC development.

Four Research Questions (RQs) are developed to guide the study to achieve the research outcomes. RQ1 is addressed to promote understanding of how to effectively manage and implement Industry 4.0 technologies and the CE as drivers of an SSC.

RQ1 How does project management support Industry 4.0 technologies and CE implementation to drive an SSC under the pandemic disruption?

The following RQs are proposed to gain a better understanding of Industry 4.0 technologies and the CE implementation barriers as well as how Industry 4.0 technologies and the CE support SSC development. Sustainable Supply Chain Management (SSCM) practices can contribute positively to firm performance, e.g., environmental and financial benefits (Paulraj et al. 2017). In this regard, RQ2 is formulated to gain insights into how Industry 4.0 technologies and the CE advance SSC development to deal with the pandemic. The framework to overcome SSC challenges has been proposed by previous research (Yadav et al. 2020). RQ3 is developed to gain an understanding of the barriers to both Industry 4.0 technologies and CE implementation which will be beneficial to the advancement of SSC development for manufacturing companies.

RQ2 What are the roles of Industry 4.0 technologies and CE in promoting an SSC?

RQ3 What are the barriers to Industry 4.0 technologies and CE implementation?

COVID-19 pandemic negatively affects the economy and supply chain activities globally (Caballero-Morales 2021). Business operations can be greatly disrupted, and actions to minimize the impacts of the pandemic are required to ensure business sustainability (Mont et al. 2021). The pandemic has also become a supply chain risk (Sharma et al. 2020) and poses difficulties for companies to cope with the changes within the supply chain (Wang et al. 2021). The rapid change in the business environment brings difficulties for SSC development (Yadav et al. 2020). Thus, the RQ4 is proposed to promote an understanding of COVID-19 effects on supply chain operations.

RQ4 How does COVID-19 disrupt a company's supply chain operations?

The following sections of the paper are structured as follows. The literature review is provided in Sect. 2 to address RQs 1 to 3 and to provide the conceptual background of our research. Section 3 presents the research methodology while the research result is presented in Sect. 4. Section 5 focuses on the combined-case analysis to answer RQ4. Lastly, Sect. 6 presents the discussion and conclusion of this research.

2 Conceptual background

This section reviews the current literature to address the RQs 1 to 3. The review of the literature begins by focusing on RQ1. The process and challenges of integrating the concepts of sustainability into project management are examined. This section also covers the concepts of Industry 4.0 technologies, CE, and SSC as well as sustainability in the metals industry.

2.1 Project management and sustainability

The Sustainable Project Management (SPM) research has passed the introductory phase with numerous open research topics and practical challenges to be addressed (Chofreh et al. 2019). To date, the process and challenges for integrating sustainability into project management have been increasingly understood with intense research in recent years. To incorporate sustainability into project management, the variables of sustainability in project management surrounding

the environmental, economic, and social dimensions must be considered for addressing sustainability issues and attaining project success. The mitigation of environmental and social impacts has been shown to create positive effects on a project's success (Carvalho and Rabechini 2017). Among the three dimensions of sustainability, the social aspect of SPM is an emerging area of the literature (Marcelino-Sádaba et al. 2015). Compared to traditional project management, SPM requires the commitment and collaboration of a wider array of stakeholders and a broader investigation of the societal context (Silvius 2017). Since the planning stage, the identification of critical project management factors at the personal, team, and organizational levels has to be made for efficient sustainable growth (Wang et al. 2017). The introduction of the three dimensions of sustainability to projects can result in the different levels of competencies and responsibility required to fulfil the role of a project manager (Toljaga-nikoli et al. 2020). The traditional way of SPM is to add sustainability characteristics to products and services only. As shown by Marcelino-Sádaba et al. (2015), the review findings suggest the need to shift away from a sole focus on the end products to a broader context, in which products, processes, organizations, and project managers are under sustainability examination in an integrated way. The selection of sustainability strategies must be carefully made considering the synergies and conflicts between the sustainability goals of projects and host organizations (Aarseth et al. 2017). The stakeholder engagement and the organization's learning process also need to occur throughout the life cycle of resources, project processes, and products to achieve effective integration of sustainability into projects (Armenia et al. 2019).

2.2 Industry 4.0 technologies and Circular Economy

The current literature related to Industry 4.0 technologies and the CE with a focus on SSC is examined to address RQ2. Big data, cloud technology, Internet of Things (IoT), Augmented and Virtual Reality (AR&VR), cyber-physical systems, robotics, and simulation (Duman and Akdemir 2021; Enyoghasi and Badurdeen 2021; Tortorella et al. 2019) are among the major technologies that drive digitalization in firms, enabling sustainable business operations and promoting resource utilization (Chauhan et al. 2021). With blockchain technology, the improvement in the transparency and traceability of a supply chain can be realized (Kouhizadeh et al. 2021), and the technology helps manufacturing companies achieve operational excellence (Upadhyay et al. 2021). The efficient data collection and sharing enhanced by Industry 4.0 technologies help firms across supply chains to achieve sustainable operations management and a more efficient circularity of resources (Lopes de Sousa Jabbour et al.

2018). The digital transformation to Industry 4.0 can lead to the improvement of product quality, production flexibility, and product development process (Cugno et al. 2021). Big data applications for carbon emission management (Kaur and Singh 2018) and green innovations (Zhou et al. 2020) play an important role in promoting a competitive advantage in the SSC of the manufacturing sector, helping manufacturing companies to achieve sustainable development targets. The implementation of Industry 4.0 technologies helps reshape the footprint of manufacturing operations and supply chains through the enhancements in data-management capabilities and opportunities for providing service-oriented products (Culot et al. 2020). Industry 4.0 technologies also support firms to move forward on sustainable pathways during disruption periods. The implementation of Industry 4.0 technologies can help develop agile process capabilities and a supply chain ecosystem that can cope with the demand disruptions during the COVID-19 pandemic (Sharma et al. 2020).

The concept of CE has attracted more attention in recent years from industrialists and policymakers due to its potential in improving resource utilization, reducing waste generation (Blomsma 2018; Moktadir et al. 2020), and creating business values (Mura et al. 2020). Well-known CE practices include 3Rs (Reduce, Reuse, Recycle), pollution prevention, product stewardship, eco-design, Life Cycle Assessment (LCA), Internal Environmental Management (IEM), green purchasing, cooperation with customers, refurbishing, and remanufacturing (Kalmykova et al. 2018; Masi et al. 2018). The positive impacts of CE projects on metals (Bendikiene et al. 2019; Tan et al. 2021), automotive (Yadav et al. 2020), and fashion (Brydges 2021) industries, have been documented by previous empirical studies. So far, the sustainability effects of CE implementation at the supply chain level are still at the early stage of development compared to the firm level (Masi et al. 2018). The integration of CE into Supply Chain Management (SCM) is known as Circular Supply Chain Management (CSCM). CSCM offers a new perspective to SSC development through the concepts of CE (De Angelis et al. 2018) and life cycle thinking at an inter-firm level (Walker et al. 2021). The forward and reverse supply chains are coordinated to prevent resource input and energy leakage (Geissdoerfer et al. 2018) and enable restorative flows of resources among organizations within or across supply chains (Batista et al. 2018). Both CE and Industry 4.0 technologies are the important basis for sustainable resource management (Ozkan-Ozen et al. 2020) and sustainable business performance (Gupta et al. 2021) of manufacturing supply chains. Industry 4.0 technologies play a key supporting role in the success of CE and sustainable development through the enhancements in smart data management (Fatimah et al. 2020), real-time

information sharing (Dev et al. 2020), and visibility of demand and inventory levels throughout the supply chain (Bag et al. 2021a; Gupta et al. 2021). At the public policy level, aside from its potential for macro-economic development and greenhouse gas mitigation, the CE can strengthen the underdeveloped social sustainability through the creation of domestic jobs required to facilitate CE activities in recycling and reuse (Geerken et al. 2019).

Here, the current literature is examined to address RQ3, identifying the barriers to Industry 4.0 technologies and CE implementation. Despite the aforementioned benefits, various barriers impose varying obligations in Industry 4.0 transition for firms across different sectors (Cugno et al. 2021; Majumdar et al. 2021) and countries with different economic levels (Raj et al. 2020). The prerequisite knowledge required by workers is among the commonly cited barriers to the efficient integration of Industry 4.0 technologies into current operations (Cugno et al. 2021; Majumdar et al. 2021). In addition, it is commonly found in the literature that the utilization of Industry 4.0 technologies requires a significant investment in equipment and infrastructure (Kerin and Pham 2019). With the rapid development of technologies, regulators and legislators also need to quickly adapt to understand the current impacts of technological innovations (Kamble et al. 2018). The barriers to CE implementation are also an emerging topic of interest and research. Masi et al. (2018) classify the main barriers to CE implementation as financial, institutional, infrastructural, societal, and technological barriers. Among these barriers, the significant upfront investment cost and the lack of awareness and sense of urgency are the main barriers to CE implementation perceived by firms from various industrial sectors. Kirchherr et al. (2018) investigate the barriers to CE implementation at the regional level, indicating that the region-wide adoption of CE business models in the EU is hindered primarily by the cultural barriers from both consumers and companies. Other studies also investigate the barriers that are similar and interconnected, but unique to the empirical context of their case studies. In the case of waste management in China, the development of responsible waste management with circular usage based on CE concepts is still at the early stage due to the lack of market pressures and demands for waste circularity (Zhang et al. 2019). For manufacturing firms in Italy, the utilization of traditional business models limits the transition to the CE model (Gusmerotti et al. 2019). Paletta et al. (2019) examine the barriers to plastics circularity in Italy based on the data from plastic converting companies whose business models are innovatively distinctive and categorize the barriers to plastics circularity in Italy as legislative, economic, technological, and social-cultural.

2.3 Sustainable Supply Chain

2.3.1 Sustainable Supply Chain Management practices

SSCM practices play an increasingly important role in achieving competitive advantages and overcoming highly uncertain COVID-19 situations. The adaptive practice, i.e., resilience, undertaken by firms aim to develop the competencies and behaviors of a supply chain required to resist and survive disruptions (Bui et al. 2021). Other desirable supply chain characteristics found in the literature include agility, visibility, ambidexterity, and advances in technology and digital resources. Love et al. (2021) study the impact of COVID-19 on the seafood supply chain. They highlight that adaptive responses need to be carried forward, and organizations should engage in building resilience to prevent impacts from a future pandemic. Agile practice enables firms with the market-sensing capability to promptly respond to changing business environments (Geyi et al. 2020; Zhu and Gao 2021). Kamble et al. (2020) conclude that supply chain visibility is the main enabler of data analytic capability and sustainable agricultural supply chain development. Supply chain resources need to be deployed to obtain good supply chain visibility, allowing actors within a supply chain to gain accurate information for pinpointing sustainable development strategies. Organizational ambidexterity is also vital in enhancing firms to be resilient to disruptions. To deal with disruption impacts, firms need to focus their operational activities on exploiting value from existing resources and exploring new business opportunities (Bui et al. 2021). While being used for the Triple Bottom Line (TBL) benefits (Silvestre and Țircă 2019), innovations could help firms to recover and survive after the COVID-19 outbreak. Digital resources allow firms to accelerate the implementation of disruptive innovations and make better use of limited resources (Caballero-Morales 2021). Rowan and Galanakis (2020) identify many disruptive technologies and innovations that can help support the supply chain of Ireland's agri-food sector to remain competitive during the COVID-19 and future pandemics.

SSCM practices related to management commitment and supply chain collaboration are also shown in the recent body of SSCM literature. Mathivathanan et al. (2018) view management commitment toward sustainability as the most influential driver of an SSC. Management involvement, support, and commitment are critical strategies to successfully implement SSCM practices by establishing an organization's vision and objectives to guide SSC development (Luthra and Mangla 2018). It is also important that management commits to increasing the level of collaboration and coordination at the supply chain level (Koberg and Longoni 2019; Huo et al. 2021). Project management

methodologies must be adopted to create effective coordination in the implementation of programs and initiatives on supply chains (Frederico 2021). Chen et al. (2017) and Choi and Hwang (2015) suggest that collaboration among firms helps the whole supply chain in achieving sustainability and strengthens an individual firm's resources and capabilities to pursue economic, environmental, and social performance goals. The ability to initiate and execute inter-organizational collaboration is referred to as a firm's collaborative capability (de Almeida et al. 2020).

2.3.2 Sustainable Supply Chain Management challenges

The integration of economic, social, and environmental aspects to increase supply chain performances is a continuing challenge in SSCM (Alkhuzaim et al. 2021). The recent SSCM research is dominated by multiple-criteria decision-making methods focusing on firm-level performances. The consideration of drivers and barriers for SSCM development in empirical studies with a more comprehensive sustainability orientation at the macro-level is suggested for a future research agenda by Khan et al. (2021). However, future studies should not overlook the importance of promoting sustainability at the micro-level. Kristensen and Mosgaard (2020) emphasize that the study of sustainability, e.g., measuring the circularity level, at the micro-level is still lacking. The evolution of SSCM perspectives has been studied in the chemical industry, and more research attention should be given to the effects of firm size on the nature and level of sustainability adoption (Rajeev et al. 2019). Moreover, the intra- and inter-organizational details of supply chains require greater attention (Rebs et al. 2019).

Recent SSCM literature shows a lack of resources and sustainability targets which can significantly hinder sustainable operations at the firm and supply chain levels. These concerns encompass the lack of skilled workforce and knowledge (Khan et al. 2021; Kumar et al. 2021), the lack of technologies and facilities to support sustainable practices implementation (Gupta et al. 2020; Khan et al. 2021; Kouhizadeh et al. 2021), the lack of organizational sustainable performance measures and targets (Gupta et al. 2020; Khan et al. 2021; Kumar et al. 2021), and the lack of capital and financial sources (Glover et al. 2014; Gupta et al. 2020; Khan et al. 2021). The selection and implementation of suitable SSCM practices require careful consideration of sustainability problems. For complex systems, economic, environmental, and social aspects need to be considered when evaluating the sustainability performances and primary stakeholders. There exist various decision support tools that support different parts of SSCM, such as supplier selection (Schramm et al. 2020), and resource utilization decision-support tools (Namany et al. 2019). These tools

are utilized based on the sustainability implications of the product, process, or system being studied. The solving of problem scenarios where sustainability development targets are at different planning levels (strategic, tactical, and operational) and across the entire life cycle stages are still open research challenges (Zahraee et al. 2020). In the context of SSC, the social impact understanding is still a less-developed domain compared to the economic and environmental aspects (Martins and Pato 2019). The adoption of social criteria is of insufficient interest according to the sustainable supplier-selection literature (Rashidi et al. 2020). In the sustainable manufacturing literature (Zarte et al. 2019), the lack of comprehensive understanding of the social sustainability aspects is because of inconsistent consideration of social impact determinants across different life cycle stages, and decision support systems focus more on integrating sustainability at the product-design phase rather than the production and control stages. In the area of sustainable consumption and production, Wang et al. (2019) indicate that the solving of consumption and production issues requires a sufficient understanding of the behavioral characteristics of stakeholders, which may vary significantly between developed and developing areas.

Identifying and understanding the key factors affecting supply chain sustainability, relevant uncertainties, and sustainability stressors are important for achieving supply chain sustainability goals. Firms need to align their limited resources and capabilities to overcome the sustainability pressure created by external factors, especially those that are uncertain or mostly uncontrollable. For instance, firms that operate in the oil and gas industry need to deal with strong public pressure to reduce pollution and unstable energy demand (Wan Ahmad et al. 2017). The development of decision support approaches also needs to be based on the sufficient consideration of uncertain parameters (Hajjigha et al. 2021). For example, multi-objective optimization tools for biomass supply chains need to be developed based on the TBL sustainability and uncertainties related to politics, government, pricing impact, and raw material cost (Zahraee et al. 2020). Firms are limited by the availability of resources in handling a variety of sustainability issues.

2.4 Sustainability in the metals industry

The metals industry contributes to the country's economic growth (Ma et al. 2014). Materials, such as iron, steel, and aluminum, are raw materials in many downstream industries. With the processing of these metals, the metals industry consumes a significant amount of energy and creates negative environmental impacts (Ma et al. 2014; Feng et al. 2019; Huang et al. 2020). The metals industry has a CE potential due to the recyclability nature of the raw materials

(de Souza and Pacca 2021). Studies in the field of environmental sciences, sustainable development, and CE could support firms to develop capability to narrow or alleviate problems (Sauvé et al. 2016). Enhancing environmental performance can improve sustainable development of the metals industry (Conejo et al. 2020; Zhang and Song 2021). Mastos et al. (2020) illustrate that Industry 4.0 technologies help promote sustainable management of scrap metal by creating positive outcomes related to pollution reduction, lead time reduction, and resource usage optimization.

3 Research methodology

This study qualitatively explores the impacts of COVID-19 on companies' operations and investigates how project management, Industry 4.0 technologies, and the CE help firms develop SSC performance to overcome business disruption. A multiple case study strategy is used to compare several business cases with a focus on COVID-19 impacts. The multiple case study approach has been adopted by the previous studies to investigate the sustainability aspect of firms (Martens and Carvalho 2016; Morioka et al. 2017), Green supply chain management (Scur and Barbosa 2017; Upadhyay 2021), and CE business models (Ranta et al. 2018). It helps investigate and compare phenomena among cases to generalize possible solutions to the disruption. Semi-structured interviews with three manufacturing companies in the Thai metals industry were conducted. With the multiple case study strategy, this research analyzes the collected data from metals manufacturing companies using both individual- and combined-case analysis, providing details of companies that participated in the study and linkage among concepts being studied.

This research begins with a literature review to determine the theoretical background and relevant concepts. The literature review findings serve as the basis for our research framework formulation and the semi-structured interviews. The multiple case study strategy is adopted to investigate the impact of COVID-19 on the company's operations, i.e., demand disruption, production disruption, and distribution disruption.

3.1 Research framework

Contingency theory is useful to study organizations operating in varying environments (Negandhi and Reimann 1972) and is a possible tool for enhancing an organization's performance (Betts 2003). Considering the uniqueness of each organization, no one best solution fits all organizations (Galbraith 1973). The best way to operate an organization depends on its environment (Scott 2003). Negandhi (1975)

focuses on the contingency theory of organizational studies having three environment boundaries including organizational environment, task environment, and societal environment. The important variables of the organizational environment include size, technology, and capital resources. The task environment is related to the organizational goals and the desired competitive advantages. The societal environment is the macro-level environment such as economic and social aspects. Tortorella et al. (2019) use contingency theory as the fundamental theory to study Industry 4.0 technologies adoption, lean production, and operational performance improvement. However, they notice that the sole focus on technology adoption might not make a significant performance improvement. Even though Industry 4.0 technologies can advance and develop an SSC (Esmailian et al. 2020), combined implementation of CE practices and Industry 4.0 technologies can further promote sustainable development (Dantas et al. 2021). Furthermore, project management can help integrate sustainability with business (Marcelino-Sádaba et al. 2015). Hence, this study considers the adoption of project management, CE practices, and Industry 4.0 technologies as part of the organizational environment to support SSC development.

Under a volatile task environment, organizations need to not only accept changes but also adapt their internal operations for business survival enhancement (Osborn and Hunt 1974). In this manner, the COVID-19 pandemic has negative effects on companies' operations, creating challenges in terms of the task environment in which companies operate (Wang et al. 2021). Risks within the supply chain, e.g., supply risks and demand risks, have increased significantly under the COVID-19 disruption (Sharma et al. 2020). Multiple stages of the supply chain could be affected by the disruption risks. Future increases in uncertainties related to demand and production might take longer to be realized (Love et al. 2021). Our study considers the interconnection of supply chain elements including suppliers, distributors, and customers as part of the environment that the company operates. The company needs to adapt its supply chain to survive during the pandemic. SSCM with supply chain agility, coordination, flexibility, and resilience could help balance supply chain disruptions and sustainability performance (Bui et al. 2021). Hence, our research focuses on SSC development as one of the key elements that help firms to overcome the crisis, since it can help them lower costs, improve efficiency, and generate long-term competitive advantages (Glover et al. 2014; Chacón Vargas et al. 2018).

The COVID-19 pandemic results in macro-level disruption with negative economic impacts and societal pressures, and manufacturing companies need to adapt to changing demand (Zimmerling and Chen 2021). Technological integration and innovation have been identified as one of the

SSCM practices (Mathivathanan et al. 2018). Industry 4.0 technologies are sources of competitive advantages (Bravi and Murmura 2021), and information sharing under Industry 4.0 technologies helps promote CE and SSC development (Dev et al. 2020). This study explores the linkage among the three environments and regards project management, CE, and Industry 4.0 technologies adoption as the supporting tools for manufacturing firms under disruption. Massaro et al. (2021) highlight how Industry 4.0 technologies positively impact CE adoption through activities, such as promoting critical resources efficiency, enhancing business models, and improving waste management.

As shown in the research framework in Fig. 1, this study investigates how project management supports metals manufacturing companies to successfully implement both Industry 4.0 technologies and the CE. Then, the linkage of how Industry 4.0 technologies and the CE acts as the enablers for SSC is determined. The proposed framework aims to satisfy both RO1 and RO2. The impacts of the COVID-19 pandemic on companies' demand, production, and distribution are explored, to indicate possible sustainable solutions.

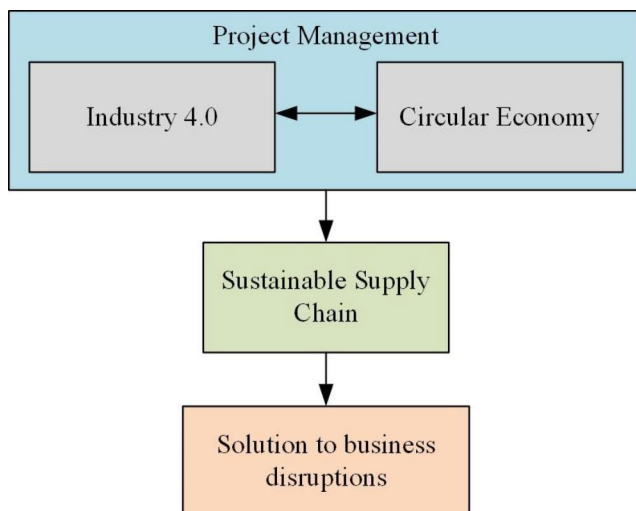


Fig. 1 Research Framework

3.2 Case study selection and data collection

Organizations are considered to be open systems that are exposed and sensitive to the environment (Scott 2003). The

organizations' ability to react to the dynamic environment is important to their survival in the competitive markets. In this study, the COVID-19 pandemic is considered as the external factor affecting the operations of metals manufacturing companies. This study adopts the multiple case study strategy allowing the study to focus on different characteristics of manufacturing firms (Morioka et al. 2017) and compare cases (Ranta et al. 2018). The participants from three manufacturing companies in the Thai metals industry, with different sizes, ages, and product types are selected to examine the different aspects of the primary organizational contingency factors as highlighted by Betts (2003) and their commonality in strategies for responding to the disruption. Metals companies in Thailand still operate with a large burden of energy consumption and pollutant emissions. The use of technologies for energy efficiency improvement in manufacturing processes is identified as an important part of the solution to reducing greenhouse gas emissions (Juntueng et al. 2014). The promotion of sustainable development for the metals industry is also essential to economic growth (Zhang and Song 2021). Also, there is a limited number of studies focusing on COVID-19 impacts in the Thai manufacturing sector especially the metals industry which could be further explored. Merli et al. (2018) suggest future research to focus on innovative practices, linked with the CE concept. The findings of the multiple case study are expected to generate insights into how Industry 4.0 technologies and the CE act as the enablers for SSC. Such knowledge can help manufacturing companies overcome the pandemic disruption and achieve sustainable development goals. The rationale for using the multiple case study strategy and semi-structured interviews to compare the results among cases and provide convincing study results is outlined by the previous research (Dieste et al. 2020; Upadhyay 2021). This study focuses on three cases in the Thai metals industry covering small-, medium-, and large-size companies. They also manufacture different types of products which could provide different aspects of how COVID-19 affects these businesses. To protect the privacy of research participants, the case studies are identified as Company A, Company B, and Company C (see the company profiles in Table 1). The primary data for this study were collected through semi-structured interviews with executives from these companies who have strong knowledge of company operations. This provides insight into how the COVID-19 pandemic affects

Table 1 Summary of company profiles

Companies details	Company A	Company B	Company C
Size*	Small	Medium	Large
Main raw material	Metal sheet	Aluminum ingot	Steel coil
Products	Metal workpieces, construction parts, and agricultural machinery parts	Cook-/kitchenware	Steel pipe, metal sheet
Years operated	Less than 5 years	More than 50 years	More than 40 years

*Size of the company is categorized by the number of employees: small (≤ 50), medium (> 50 but ≤ 200), and large (> 200)

these businesses and promotes the understanding of how project management, Industry 4.0 technologies, and the CE drive SSC development, resulting in long-term sustainable development and possible solutions to the pandemic.

3.3 Data analysis

This study consists of two main types of data analysis including individual company analysis and combined-case analysis (Upadhyay 2021). The individual analysis provides details of each manufacturing company that participated in the study to promote the understanding of the context of each company as presented in Sect. 4. The collected data from each company is presented based on the individual company context, covering the company's current business status and how COVID-19 affects its operations. Moreover, the adoption of Industry 4.0 technologies and CE with the linkage with project management is presented in this section. The individual analysis also provides details on how Industry 4.0 technologies and the CE help these firms drive an SSC.

In Sect. 5, combined-case analysis allows the study to determine the linkage among the concepts with different contexts of companies. The combined-case analysis is performed to determine if there are common phenomena or factors affecting companies' operations and sustainability. The combined-case analysis provides insight into the aspects of how the pandemic disrupts demand, production, and distribution as well as how project management supports these companies during the pandemic. Furthermore, the study also focuses on how companies move from reactive to proactive actions as the long-term solution to disruption.

4 Research result

This section presents the overall information about the companies and analyzes the companies that participated in this study individually. Moreover, the interview results are summarized in the dimensions of COVID-19 disruption, project management for Industry 4.0 technologies and CE adoption, SSC development, and reactive and proactive solutions to the pandemic.

4.1 Company A

Company A is a small company that has been manufacturing metal products from metal sheets for less than 5 years. The products are used as parts for building and rail construction, tractor and trailer assembly, etc. The company invests in high-capability machines that are capable of manufacturing various types of products, making it possible to satisfy

a wide range of customer demands. Moreover, the company emphasizes agile practice with a target to operate with the optimal number of employees. Employees need to be multi-skilled and capable of operating various types of machines, and hence rotating employees is possible when required. The interviewee mentions that *"Our company has a small number of employees. Since we established the factory, we have a target and policy to use technologies to support working activities, helping us to have fewer employees."* The company has already adopted Industry 4.0 technologies such as IoT, data analytics, cloud technology, automation, robotics, and simulation. The company notices that Industry 4.0 technologies can support employees to perform repetitive tasks effectively, resulting in cost savings and a smaller number of employees. However, implementation of Industry 4.0 technologies is still limited and not fully deployed to the entire organization due to limitations during the transition process.

Even though COVID-19 has had a strong negative impact on SMEs with sensitive supply chains (Caballero-Morales 2021), Company A diverts its resources to focus on offering new products and services for local customers and gaining a new market share in agricultural machinery. The new business opportunities have helped the company from being financially insecure by the pandemic. Moreover, the company adopts CE practices, e.g., remanufacturing and recycling, to reduce costs and commit to sustainable development. The interviewee states that there are no leadership barriers to Industry 4.0 technologies adoption. However, the company still has not fully implemented Industry 4.0 technologies due to the high capital investment and the lack of knowledge and skill. The company views project management as an essential element to support CE practices and Industry 4.0 technologies implementation. A strong connection between the organization, project leaders, team members, and products is achievable through project management, supporting both CE practices and Industry 4.0 technologies adoption. In terms of an SSC, the company emphasizes the relationships with customers and commits to satisfying customer needs for products and services. The adoption of innovation helps the company to supply high-quality products and solutions to customers. The company also elaborates that the COVID-19 pandemic is the driver for SSCM practices adoption and sees agile practice as one of the essential elements of an SSC. Therefore, multi-skill training is one of the main priorities for the company to remain competitive in the market. The company also sees benefits from multi-level collaboration within the supply chain network, and the company is working with customers to better understand customer requirements during the new product development process. The important findings

Table 2 Interview summary of Company A

Company A		
	Interview Summary	Selected Interview Quotations
COVID-19 disruption	<ul style="list-style-type: none"> The company has shifted its focus to meet the needs of customers that are not severely affected by the pandemic. This demonstrates the company's ability to minimize the impacts of the COVID-19 pandemic on the company's operations by picking the right market segment and adapting to the changing demands. During the pandemic, the company relies more on product customization to capture local customer demands for agricultural machinery parts. The company prioritizes the adoption of digital technologies to minimize the required workforce, resulting in improved cost control. Moreover, the company has already adopted agile practice to create cross-functional teams and promote flexibility on its production site. Adopting digital technologies on the production site helps promote the working conditions and reduce production time and cost. 	<p>"The local demands in some sectors have not been significantly affected by the COVID-19 pandemic. For example, the demands of our customers who make agricultural machinery have not been noticeably affected by the pandemic, as agricultural activities continue amidst COVID-19."</p> <p>"We have entered this market and gained market share so there has been limited impact on the sales and demand from this customer group."</p> <p>"We have already adopted agile practice [...]. Our employees need to be able to perform a range of tasks [...]. This also contributes to SSC development [...]. The employees are interchangeable."</p> <p>"Industry 4.0 technologies help increase manufacturing speed, quality, and safety [...]. Technologies, including automation, robotics, and IoT, help promote the manufacturing capability"</p>
Project management for Industry 4.0 technologies adoption	<ul style="list-style-type: none"> Project management plays an important role in supporting the company to adopt Industry 4.0 technologies. Currently, the company's management team has already recognized the benefits of adopting Industry 4.0 technologies. However, the successful transition process is the major challenge to Industry 4.0 technologies adoption, and a higher effort is required to fully implement and integrate Industry 4.0 technologies with the company's operations. The understanding of Industry 4.0 among the employees is limited. Top management needs to communicate its commitment to implementing Industry 4.0 technologies to improve processes and achieve operational goals. Industry 4.0 technologies support the company's operations and help control the products' quality. The company's management team believes that Industry 4.0 technologies help promote business survivability in the future. 	<p>"Project management supports the Industry 4.0 transition process, and the success of Industry 4.0 technologies implementation depends on this process. We as the top management do not have barrier for Industry 4.0 technologies."</p> <p>"In terms of Industry 4.0 technologies adoption challenges, we believe that some employees still lack an understanding of Industry 4.0. Hence, we need to communicate with them [...]. The most important thing is still the targets that the company sets."</p> <p>"Industry 4.0 technologies help control product quality [...]. Cloud technology has been adopted so that the data can be accessed remotely [...]. We also use data analytics in our sales department [...]. The technologies also help save the earth by going paperless."</p> <p>"We are working on business transformation to be ready for the future, and this is also the driver for Industry 4.0 technologies adoption. We need to be prepared, to survive in the future."</p>
Project management for CE adoption	<ul style="list-style-type: none"> Project management supports the alignment of stakeholders to achieve CE adoption. However, the company currently regards cost reduction as the main factor to survive in the competitive environment. Since environmental performance is not the priority, it will take time to fully implement CE. Furthermore, a lack of knowledge and understanding leads to difficulties in communicating the importance of the CE concept to internal and external stakeholders. 	<p>"Implementation of CE does not rely on a single party. All stakeholders in project management, including team members, project leaders, organization, etc., need to work together to achieve CE adoption."</p> <p>"For CE challenges, the business is still in the initial stage, where cost is the major concern to survive in the market. So, the environmental aspects still have a lower priority [...]. Also, people (within the organization and customers) still lack an understanding and knowledge of the concept."</p>
How Industry 4.0 and the CE drive SSC development	<ul style="list-style-type: none"> The company sees having good supply chain relationships as one of the main factors to create business sustainability. Thus, the company focuses on addressing customer needs, building customer relations, and committing to customer service. Innovation helps improve the business model, reduce cost, and enhance product quality. Industry 4.0 technologies and the CE support company development and help address future customer needs. Furthermore, they also improve the company's competitive advantages by improving resource efficiency and capability. Digital technologies promote the efficiency of business operations. Cloud technology helps enable effective customer support and enhances data access and sharing. CE practices improve labor conditions and reduce the negative effects on stakeholders. 	<p>"We see business sustainability as having good supply chain relationships and high quality of services, and satisfying customer needs. If we could not satisfy the customer needs, then they will seek other suppliers."</p> <p>"Innovation is important. When we have new ideas or innovation, we present them to customers [...]. We can use innovation to support our customers, improve product quality, and reduce costs."</p> <p>"We aim to adopt Industry 4.0 technologies and CE to better address customer needs in the future [...]. For our organization, we see Industry 4.0 technologies and the CE as the elements that push internal development, making us stronger to survive in the future [...] and increase competitive advantages."</p> <p>"Digital technologies make the business process easier with higher efficiency. Cloud technology helps facilitate customer support"</p> <p>"CE practices help improve working conditions, and we believe that they help reduce the impacts on the stakeholders."</p>

Table 2 (continued)

Company A	
Interview Summary	Selected Interview Quotations
<p>Industry 4.0, the CE, and an SSC: Solution to the pandemic</p> <p>Handling and overcoming disruptions:</p> <p>Reactive solution</p> <ul style="list-style-type: none"> • Industry 4.0 technologies, CE, and SSC adoption help the company to improve its business operations and create a new business model that better addresses customer needs during the COVID-19 pandemic. • Currently, the implementation of digital technologies and CE is still in the early stages of development. The company sees the long-term potential benefits of fully integrating digital technologies within the company's operations. • Waste reduction (3Rs) directly reduces the company's manufacturing cost. • Good supply chain relationships are crucial to develop an SSC. The company believes that creating an SSC will promote business survival in the future. <p>Proactive solution</p> <ul style="list-style-type: none"> • The company needs to improve continuously and be active, alert, and stable. Customer requirements change rapidly, and the company needs to be ready to adapt to those changes. • Digital technologies make business processes leaner by reducing the number of business processes. • Expanding CE practices adoption is under the company's long-term development plan. The company expects CE practices to further help reduce costs. 	<p>Reactive solution</p> <p>“We change the way of working to better satisfy customer needs.”</p> <p>“COVID-19 expedites us to migrate to technology-intensive manufacturing.”</p> <p>“In the short term, digital technologies adoption is under the trial and learning phases.”</p> <p>“Currently, CE practices have already helped us to reduce costs.”</p> <p>“For waste reduction, after having scraps left over from the production processes, we use them to manufacture small products until the size is too small. Then, we send them for recycling.”</p> <p>“In terms of an SSC, we see having good relationships with suppliers and customers as one of the most important elements [...]. Supply chain collaboration is the result of having good relationships. With good supply chain relationships, we can solve problems quickly”</p> <p>Proactive solution</p> <p>“Within 5 to 10 years, the technologies will make the business processes easier and help us reduce the required number of processes.”</p> <p>“We view the adoption of CE practices as the long-term solution [...]. We believe that CE practices are key to future cost reductions.”</p> <p>“We need to make sure that our employees know how CE practices can be implemented to improve our businesses.”</p> <p>“Also, the successful implementation of CE practices such as LCA requires mutual understanding from all parties, including customers and suppliers.”</p> <p>“We need to be ready to adjust ourselves [...]. Being active, alert, and stable is important. Continuous improvement is also very important. We are under the disruption era [...]. Customer requirements change rapidly [...]. Management teams need to circulate and deploy ideas for changes in the organization.”</p>

and interesting quotations obtained from the interview with Company A are summarized in Table 2.

4.2 Company B

Company B is a medium-sized company that manufactures aluminum cookware as well as aluminum products with traditional Thai patterns crafted on the surface. The company has two manufacturing sites located close to each other. The first manufacturing site consists of a smelting operation and sheet aluminum rolling processes, which turn aluminum ingot or recycled aluminum, e.g., aluminum electrical wire, into aluminum sheets. The second manufacturing site has operations that turn the aluminum sheets into the final products by pressing and pattern-stamping processes. The company has already adopted some Industry 4.0 technologies, mainly including data analytics, automation, simulation, and cloud technology. Nevertheless, the implementation of these technologies is still limited and not fully integrated due to existing limitations, e.g., lack of top management commitment, lack of knowledge, and high capital investment.

The company's main business model is B2B, in which its financial status relies heavily on the sales of products to

distributors. The relationships with the distributors are crucial for the company to survive in a highly competitive environment, with demand shifting from aluminum to stainless steel cookware products. The company needs to rely heavily on the sale of its signature products, e.g., aluminum cookware with traditional Thai patterns and designs. However, the demand for these signature products is seasonal. The current production strategy, which is highly push-production oriented, creates growing stock levels of products that are sufficient to cover the peak seasonal demand periods.

The company sees project management as a key to achieving business sustainability as mentioned by the interviewee: “*For business sustainability, project management is indispensable. Cost reduction is one of the main factors that drive project management. We are under the exploration phase to determine which projects can help sustain our organization and are working on infrastructure improvement to sustain the business.*”. The company recognizes cost reduction as the main benefit of Industry 4.0 technologies adoption. Before the pandemic, a lack of top management commitment was the main organizational barrier to the adoption of Industry 4.0 technologies and SSC innovation. However, the company perceived the pandemic as a threat

Table 3 Interview summary of Company B

Company B		
	Interview Summary	Selected Interview Quotations
COVID-19 disruption	<ul style="list-style-type: none"> • Only 20% of the pre-pandemic demand level remains during the COVID-19 pandemic. • The company has experienced an unexpected loss in demand for event-driven products. However, the company notices new demand for products with potential sanitation concerns, e.g., personal dinnerware, in the surge of COVID-19 cases. • The company needs to handle a large amount of inventory due to the loss of demand. • Employees' working hours need to be reduced, to save cost and reduce excess production capacity. 	<p>“Overall, COVID-19 negatively affects the sales of the company (20% of normal sales). However, the COVID-19 pandemic also creates new demand for some product types. For example, some customers/organizations ask for individual-serving dinnerware, such as individual platters, bowls, and cups, for their employees.”</p> <p>“Initially, we maintained the same production capacity despite the lower sales due to the pandemic. By constantly producing more than demand, the inventory rose by up to 5 times, compared to the normal situation before the COVID-19 disruption.”</p> <p>“We then manage the manufacturing capacity by reducing employees' working hours and cutting overtime.”</p>
Project management for Industry 4.0 technology adoption	<ul style="list-style-type: none"> • Project management supports Industry 4.0 technologies adoption by aligning the organization, employees, and top management, leading to the successful adoption of digital technologies. • Project management, along with Industry 4.0 technologies, has positive impacts on sustainable development. • Industry 4.0 technologies help the company to save costs, reduce waste, and promote safer working conditions. • COVID-19 is the driver for the company to adopt digital technologies, e.g., cloud technology and simulation (3D-design), to create a new business model and shorten new-product development cycles. Simulation supports the company to offer product customization, resulting in expanded market opportunities. • Lack of knowledge, financial investment, and management commitment are the main barriers to Industry 4.0 technologies implementation. The company needs to overcome these barriers to fully adopt Industry 4.0 technologies. Therefore, the adoption of Industry 4.0 technologies is a continuous and gradual process over time. 	<p>“Project management links together the organization, employees, and top management and has a positive influence on the success of Industry 4.0 technologies adoption. Industry 4.0 technologies also support sustainable development by improving the employees' working conditions, productivity, business processes, and inventory management, resulting in business sustainability.”</p> <p>“COVID-19 expedites the business cycle, so the company needs to seek new developments, markets, products, and process improvement. Because of the disruption, we spend time focusing on Industry 4.0 technologies implementation to create new business opportunities.”</p> <p>“We also use 3D-design and simulation to develop new products and packaging [...]. We see the benefits of cloud technology as time reduction and easy access to stored data”</p> <p>“There are some barriers to the adoption of Industry 4.0 technologies. Employees still lack knowledge [...]. The financial investment to fully implement Industry 4.0 technologies is also high [...]. Investing in some digital technologies is not tangible, compared to new machine investment. However, we believe that the result of the investment is measurable.”</p> <p>“When the management level is not familiar with new technologies, this limits the adoption of new tools that support SSC development.”</p>
Project management for CE adoption	<ul style="list-style-type: none"> • The company is currently working on the “Buy-back” project to close the loop of the supply chain by turning end-of-life products into raw materials. SPM is an essential element, contributing to the success of this project. • The company sees employees as one of the most valuable assets. The company prioritizes IEM practice to improve the working conditions and the health and safety aspects of employees. • The company minimizes scraps from the manufacturing processes by continuously improving process control. Furthermore, refurbishing and remanufacturing help the company to reduce the required new raw materials. The recovery of metal value from scraps and defects results in cost savings. • Lack of know-how and proper framework are the main barriers to implementing CE and closing the loop of the supply chain. 	<p>“We believe that project management supports CE adoption. Project management is already embedded within the company's operation.”</p> <p>“We are currently developing the “Buy-back” project in which we will buy end-of-life products back and use them as raw materials, to close the loop of the supply chain. This also helps the company to promote a green image.”</p> <p>“We adopt refurbishing and remanufacturing practices to reduce waste in the production process.”</p> <p>“We try to minimize scraps and defects from manufacturing operations first, before going through the subsequent reclamation process [...]. CE practices help us reduce raw materials usage.”</p> <p>“We prioritize health and safety in the workplace, and IEM practice has been adopted to improve the working conditions of employees.”</p> <p>“There are some limitations on CE implementation. We still lack the know-how to make processes greener [...]. We also lack a proper framework to close the loop of the supply chain.”</p>

Table 3 (continued)

Company B		
	Interview Summary	Selected Interview Quotations
How Industry 4.0 and the CE drive SSC development	<ul style="list-style-type: none"> • The company sees Industry 4.0 technologies as the tools that help support and track CE implementation. • Industry 4.0 technologies with CE adoption enhance the company’s environmental performance and support SSC development. • The company recognizes the adoption of digital technologies as the precursor to business sustainability. The technologies help promote new business opportunities and free up time for management to focus on business process improvement. • Cloud technology adoption promotes SSC development, data transparency, and better analysis of data related to production, inventory, and accounting. 	<p>“We believe that Industry 4.0 technologies can help track and support CE adoption, leading to sustainable development [...]. We start with the questions “How do we sustain the business?” and “What tools can help sustain the business?”.”</p> <p>“We see Industry 4.0 technologies and CE practices as the tools to promote environmental performance and help create an SSC.”</p> <p>“Industry 4.0 technologies can improve business sustainability and create new business opportunities. They also help reduce process inefficiency, giving us more time to focus on business development.”</p> <p>“We are transitioning our accounting system to a cloud-based system [...]. Cloud technology helps in terms of process improvement, leading to better data accuracy, speed, inventory management, and accounting system.”</p> <p>“Innovation such as cloud technology for inventory management could support the development of an SSC.”</p>
Industry 4.0, the CE, and an SSC: Solution to the pandemic	<p>Handling and overcoming disruptions:</p> <p>Reactive solution</p> <ul style="list-style-type: none"> • Digital technologies are essential to support company operations during the COVID-19 pandemic. For example, virtual meetings, contactless automation, and an inventory management system have been used. • The COVID-19 pandemic motivates the company to overcome barriers to Industry 4.0 technologies implementation. The management team recognizes the benefits of Industry 4.0 technologies to support company operations and promote operational performance during the pandemic. • CE practices, e.g., waste reduction (3Rs), support new product development as waste from the R&D process can be recycled and turned into raw material, resulting in cost reduction. • Collaboration with suppliers and having good supply chain relationships help the company to save costs during the pandemic. For example, the company responds to supplier suggestions and achieves cost saving through the use of alternative consumables. <p>Proactive solution</p> <ul style="list-style-type: none"> • In terms of business model, the company changes its focus from being cost-competitive oriented to product customization oriented to differentiate itself from competitors. • The company recognizes the benefits of Industry 4.0 technologies in promoting operational performance, including time, quality, safety, and cost improvement. • Being different from competitors generates competitive advantages for the company. Industry 4.0 technologies, the CE, and SSCM are the essential elements, driving the success of a new business model. 	<p>Reactive solution</p> <p>“During the COVID-19 disruption, technologies allow a business to run with social distancing [...].”</p> <p>“The disruption lowers barriers to technology adoption.”</p> <p>“In-house smelting operations and recyclability of the scrap materials allow the company to improve and develop products, by adjusting thickness and developing new patterns, without creating any aluminum waste. We can remelt the aluminum wastes and turn them into raw material.”</p> <p>“We adopt agile practice in which the roles of employees are rotatable, depending on the workload of each manufacturing operation.”</p> <p>“Collaborative relationships with supply chain partners can help the company during the pandemic. For example, our distributors provide input for us to manufacture the products that have demand during the pandemic [...]. Our suppliers also suggest alternative consumables that can be used in the manufacturing line to save costs.”</p> <p>Proactive solution</p> <p>“We expect Industry 4.0 technologies to help improve time, quality, safety, and cost control [...].”</p> <p>“The disruption shapes a new business model, giving awareness for the importance of product customization [...]. We try to move from a cost-competitive and mass production market to product customization. This is one of the possible ways to sustain the business.”</p> <p>“Offering product customization helps us to create new competitive advantages and to differentiate from the competitors [...]. Industry 4.0 technologies, the CE, and SSCM support and expedite the process of business differentiation.”</p>

that amplifies the need to adopt Industry 4.0 technologies to improve business operations. As a result, the company decided to use the business development budget to improve its operations by implementing Industry 4.0 technologies on a larger scale. The company strongly believes that Industry 4.0 technologies help improve working conditions, productivity, business processes, and inventory management, leading to improved business sustainability. The company currently targets to expand the implementation of cloud technology and machinery-related Industry 4.0 technologies

and to improve production data visibility through IoT and sensors. However, the full implementation of digital technologies might take time due to the high capital investment and limited technical expertise, so the transition process to fully implement Industry 4.0 technologies is a gradual process over time.

In terms of business positioning, before the COVID-19 disruption, the company prioritized cost reduction and mass production, offering a wide range of products to customers. The company had been one of the main manufacturers in

the market with good sales. During the COVID-19 disruption, the company's sales decrease significantly. To sustain the business, the company changes its business model, from being cost-focused to driving new business value through product customization. The company needs to move from a highly competitive environment to a higher-profit margin market, where product quality is of major concern. The company has allocated its limited budget for Industry 4.0 technologies adoption to improve business operations and move towards product customization. Currently, the presence of B2C business helps create higher competitiveness and new business opportunities.

Project management is perceived by the company as the crucial element that assists the transition to the new product customization business model. The interviewee also states that project management links the organization, employees, and top management together and has a positive influence on the success of Industry 4.0 technologies implementation. The adoption of Industry 4.0 technologies together with CE is believed to be the solution to minimizing costs and supporting a new business model with improved environmental performance, helping the company to create long-term sustainable development. The potential of Industry 4.0 technologies in supporting the development of new products and new business models is pointed out by Tortorella and Fettermann (2018). The details of the interview are summarized in Table 3.

4.3 Company C

Company C is a large steel manufacturing company that has steel pipes and metal sheets as its main products. The main raw material is steel coil. The manufacturing processes turn steel coil into steel pipe through forming processes. Originally, the company offered 6-meter steel pipes with various thicknesses and diameters. Metal sheet products have later been included as one of the recent product lines. The company's production process is to cut steel coil into metal sheets of various sizes. With the presence of Industry 4.0 technologies, the company has realized the need to upgrade the existing machines mainly to resolve the issues of unreliable data collection and to enable data synchronization. The upgrading of the existing machines using sensors and IoT technology offers the company a more cost-effective solution as opposed to replacing them with new machines with Industry 4.0 technologies. Big data and data analytics are then used to manage and analyze the collected data to optimize the manufacturing processes. It is worth noting that Industry 4.0 technologies such as Big data, data analytics, cloud technology, IoT, automation, robotics, and simulation have been implemented to support the company's operations. The main benefits achieved through the

implementation of Industry 4.0 technologies include cost visibility, accurate manufacturing cost estimation, and the ability to monitor and track manufacturing costs. These enhancements are vital for the company to survive in a low-margin environment.

Currently, the company is working on creating new demand and a new business model to become a solution provider. The company focuses on product customization and fabrication, which supports its customers with in-house assembly processes of steel structures. The new business model requires collaboration with supply chain stakeholders. For steel structure products that target construction customers, product fabrication or customization reduces construction time, saves cost, and creates new designs. The company also focuses on providing new knowledge for its customers as mentioned by the interviewee: *"Once we educate our end-user customers, we can create new demand in our supply chain and a new business model that creates an SSC. We need to transform from being only a manufacturer and seller to a consultant."* Furthermore, product customization helps customers reduce waste and excess materials. The environmental problems related to construction waste are also minimized.

Project management supports the company to implement Industry 4.0 technologies and CE practices. The company recognizes the benefits of project management in aligning projects to goals, controlling project timelines, managing budgets, and acting as the center to control and link all related parties. From the company's point of view, to promote project success, several key project management factors must be addressed. For instance, during the initial stage of project management, top management plays an important role to support a project's conceptual development. After that, proper communication is necessary to turn concepts into actions. Moreover, it is important to align the employees' mindsets toward the organizational goal.

During the disruption, a labor shortage is one of the main problems of customers in the construction sector. Being a solution provider, the company can solve its customers' problems, as stated by the interviewee: *"Constructing a building with steel structure can save cost, time, and the number of required workers. Pre-fabricated steel parts provided by the company can help our customers during this disruption period. The COVID-19 pandemic is a catalyst for the usage of pre-fabricated steel parts. Product customization changes our business model. We determine the limitations of our customers including time, cost, and design. Hence, we use Industry 4.0 technologies to support them."*

The company sees the trend of green products and customer requirements as the main drivers for CE adoption. However, since the company is in a cost-competitive environment, it takes time to fully become green due to high

Table 4 Interview summary of Company C

Company C		
	Interview Summary	Selected Interview Quotations
COVID-19 disruption	<ul style="list-style-type: none"> • On the supply side, the company is facing an increase in the raw materials price. • The demand has been reduced, compared to the normal situation before the pandemic. • In response to the COVID-19 outbreak, the company minimizes the risk of infection in the workplace by assigning each group of workers to a specific production line. Moreover, lifting and handling equipment is used to move the raw materials and products across the factory, which helps minimize employee close contact. • Even though the distribution of products for the domestic market is not significantly affected by the pandemic, the cost of overseas shipping of raw materials has increased significantly. 	<p>“Despite the demand reduction, the shortage of supply is larger, resulting in the raw material price increase.”</p> <p>“Our new task assignment strategy ensures social distancing among employee groups. Each group of employees is assigned to only a specific production line. If any of our employees in a production line is infected by COVID-19, only a single production line will be contaminated. We also separate the canteen, shift supervisor, etc., to prevent cross production-line infection.”</p> <p>“We use approximately 10–20% of imported raw material and accessories in the production line, and the cost of overseas shipping has remarkably increased. In terms of distributing products to local customers, the disruption causes a minor impact. Our truck drivers strictly comply with the company’s COVID-19 infection prevention and control measures.”</p>
Project management for Industry 4.0 technology adoption	<ul style="list-style-type: none"> • The company recognizes the benefits of project management as a tool that supports Industry 4.0 technologies adoption by controlling costs, timelines, and resources. Moreover, project management is the center to control a project’s progress, guiding the project to reach its goal. • Even though the company has already adopted some Industry 4.0 technologies, there remain numerous challenges to implementing Industry 4.0 technologies. Some employees lack the understanding of the concept which limits the implementation of the technologies. Furthermore, the integration of new technologies with current operations requires strong knowledge. The return on investment in Industry 4.0 technologies for some functions, e.g., IT, HR, and marketing, is hard to estimate. • In terms of production, Industry 4.0 technologies help reduce manufacturing costs and time and increase quality, resulting in better competitive advantages in a low-profit margin environment. • Industry 4.0 technologies also support functions such as HR, sales, product distribution, and marketing, contributing to process development. Furthermore, the company targets to use machine learning to create new competitive advantages. 	<p>“For Industry 4.0 technologies adoption, project management helps analyze if a project is feasible and aligns with the company’s policies. Then, project management helps in controlling and synchronizing the working system. For example, it helps manage timelines, budgeting, number of employees involved, amount of workload, and other resources that contribute to the success of the project.”</p> <p>“The challenge of Industry 4.0 technologies adoption is that people lack an understanding of the technologies [...]. Financial investment is another concern. It is difficult to calculate the return on investment for IT, HR, and marketing systems. Hence, proper understanding and strategy need to be set for Industry 4.0 technologies adoption.”</p> <p>“The Industry 4.0 technologies help us to accurately identify, track, and save cost, so we know how to promote competitive advantages and effectively expand the business. With accurate cost information, we can better manage marketing and target customer groups that have a higher profit margin.”</p> <p>“[...] we are moving toward machine learning which combines opportunities, sales information, market conditions, and other factors to create competitive advantages [...].”</p>
Project management for CE adoption	<ul style="list-style-type: none"> • The company realizes that project management can support CE implementation as well. • Green trends and new requirements from customers create the demand for CE implementation. In general, steel is recyclable. Therefore, wastes, e.g., steel scrap from the industry, usually have a high value. CE practices help the company to minimize waste. • The company collaborates with customers to customize products, helping customers to reduce construction time, waste, and cost. 	<p>“[...] project management plays a similar role in supporting CE adoption as when it supports Industry 4.0 technologies adoption [...].”</p> <p>“We see trends for green products and customer cooperation (in terms of product requirements) as the main drivers for CE implementation. As competition in the market increases, CE practices support us to reduce manufacturing costs [...]. The company’s green image is important for some of our customers.”</p> <p>“Using steel building structure can significantly reduce dust during construction, compared to concrete, and steel is recyclable after the end-of-life stage.”</p> <p>“We collaborate with customers in terms of product design, waste reduction, and cost reduction [...].”</p>

Table 4 (continued)

Company C		
	Interview Summary	Selected Interview Quotations
How Industry 4.0 and the CE drive SSC development	<ul style="list-style-type: none"> The company sees innovation as one of the elements to develop an SSC. Multi-tier collaboration with suppliers and customers is necessary to create innovative products. IoT systems and Industry 4.0 technologies enable effective information sharing among supply chain members. The CE has been found to promote the usage of recyclable steel products. CE practices and Industry 4.0 technologies help increase product value and contribute to cost reduction, and speed and quality improvement, which create sustainable development. 	<p>“[...] innovation affects the whole supply chain [...].”</p> <p>“An SSC creates new opportunities for our company to grow. We expand our factory’s capability to be able to produce fabricated steel products, allowing us to reach new markets and create new S-curves for our business.”</p> <p>“The CE drives the usage of steel, as the material is recyclable. Industry 4.0 technologies help us to better analyze the actual cost of producing products and improve the quality of products. CE practices and Industry 4.0 technologies help reduce costs, directly and indirectly. They also help increase the value of products and differentiate us from competitors in terms of product quality and speed improvement.”</p> <p>“To develop an SSC, we need to invest in IoT systems to obtain information. Industry 4.0 technologies provide a linkage among members in the supply chain [...].”</p>
Industry 4.0, the CE, and an SSC: Solution to the pandemic	<p>Handling and overcoming disruptions:</p> <p>Reactive solution</p> <ul style="list-style-type: none"> Industry 4.0 technologies, e.g., cloud technology, allow working remotely during the COVID-19 pandemic. Moreover, Industry 4.0 technologies help the company to generate competitive advantages since the technologies support the company to collect and analyze data from the company’s operations and find ways to optimize manufacturing costs and improve sales activities. CE practices play an important role in helping customers to reduce costs. Customers seek solutions to minimize waste. Therefore, the company offers product customization that meets customer needs during the pandemic. Supply chain collaboration is essential to obtain raw materials at a reasonable cost. <p>Proactive solution</p> <ul style="list-style-type: none"> The company initiates new markets by creating engagement in supply chains and offering new products to promote competitive advantages. COVID-19 has hastened development in the industry. The company sees the potential of Industry 4.0 technologies to strengthen the bonding of members in the supply chain. 	<p>Reactive solution</p> <p>“We fully use cloud technology to support a work-from-home environment. Industry 4.0 technologies help us to identify costs and promote competitiveness. Using databases and information from Industry 4.0 technologies, we can identify potential customers and sales activities that generate a high-profit margin. For production, we use data obtained from IoT system to identify and calculate costs.”</p> <p>“Customers also focus on waste reduction, so more customers order customized products.”</p> <p>“The CE is at the strategic level to improve our organization. We seek a marketing method that creates new market demand, for example, green products demand.”</p> <p>“For an SSC, we need to collaborate more with customers and suppliers. We collaborate with suppliers to obtain raw materials during a shortage period, and we also help customers to minimize waste.”</p> <p>Proactive solution</p> <p>“When we adopt an SSC, change a sales pattern, and initiate a new business model, we create linkage within the supply chain and have unique advantages over competitors [...]. Industry 4.0 technologies support collaboration and bonding in the supply chain.”</p>

financial investment and the original cost-oriented mindset. The company now emphasizes the implementation of CE practices such as eco-design and cooperation with customers by offering make-to-order lengths and customization of steel pipes. This can help customers to reduce scrap from unnecessary cuts of steel pipes. Product customization under the CE and Industry 4.0 technologies helps mitigate the issue of labor shortage in supply chains by reducing the number of workers required. Products can be manufactured according to the required specifications, leading to cost reduction, speed improvement, and quality increase, especially for customers in the construction sector. The details of the interview are presented in Table 4.

5 Combined-case analysis: Exposing the impacts of COVID-19 disruption and the role of project management, Industry 4.0 technologies, Circular Economy, and Sustainable Supply Chain during the pandemic

In this section, the impacts of the COVID-19 pandemic on companies’ supply chains are analyzed in the dimensions of demand, production, and distribution disruptions, as adapted from the study of Love et al. (2021). This section also satisfies the proposed RQ4. The role of project management during the pandemic is analyzed, to promote an understanding of how it supports organizations to drive SSC development. The reactive and proactive solutions to the pandemic are discussed.

5.1 Demand disruption

Company A and Company C have their customer bases that are the result of offering product customization to meet the market requirements. For example, Company A offers customized products such as agricultural machinery and construction parts, while Company C produces fabricated steel structures for customers in the construction industry. For Company A, sales have not been markedly impacted during the disruption because of the ability to adapt to the changing demand. The company targets local customers from the agricultural sector who have not been significantly affected by the pandemic. Since Company C has faced demand disruption for the mass-produced products, the company focuses on a higher-margin business model, e.g., the steel structure fabrication business, with the support of Industry 4.0 technologies. These technologies help strengthen the connection among processes, resulting in an improvement in optimization, quality, and flexibility. The adoption of Industry 4.0 technologies allows better product customization (Naeem and Di Maria 2022) and collaboration among members of the supply chain (Manavalan and Jayakrishna 2019). With the COVID-19 disruption, the level of importance of product customization being offered by Company A and Company C has increased even more. As highlighted by Company C, the company has been able to adapt to new markets and demands through the product customization business model. Supply chain collaboration also contributes significantly to helping Company C to sustain its competitiveness during the COVID-19 crisis. The company focuses on exchanging information within the supply chain and educating other members in the supply chain to create new business opportunities and develop an SSC. This aligns with the conclusion of Liao et al. (2017) that supply chain collaboration helps to develop supply chain capabilities and results in competitive advantage enhancement.

Before the pandemic, Company B focused on mass production and cost minimization. The company was positioned in a highly competitive environment where cost is a major concern. However, the demand disruption caused by the pandemic heavily affects the company's sales, resulting in a significant level of excess inventory of seasonal and festival-related products. This brings attention to the company's management to consider the need to move from a cost-competitive environment to a higher-margin business model. The impact of the demand disruption makes the company aware of the importance of the product customization business model to improve its profit margin, where quality improvement is of higher concern than cost reduction.

5.2 Production disruption

In terms of production, Company C, which deals with the early stage of the steel supply chain and has steel coil as the main raw material, notices the impact from the limited supply and increase in the raw material price. Company C realizes the sustainable business development from the adoption of Industry 4.0 technologies. The company focuses on the adoption of IoT technology to enable accurate cost tracking that helps in creating a competitive advantage. The company also adopts automation and robotics technologies to perform some of the manufacturing tasks, resulting in a higher quality of products. To control the transmission risk of COVID-19, the isolation of production lines is implemented to limit the transmission of COVID-19 across production lines.

For Company B, the loss in demand impacts the company's production activities and causes the inventory level to rise significantly. The company cuts down employees' working hours and its production capacity to reduce costs. Cloud technology has been adopted to promote the effectiveness of inventory management. The company has adopted simulation technology to support the product customization business model that is believed to help the company move away from the cost-competitive environment. However, Industry 4.0 technologies are still not fully implemented and integrated into business operations. The company still needs to find a financially feasible way to adopt Industry 4.0 technologies on a wider scale. Industry 4.0 technologies can potentially promote mass customization which is crucial for the success of the new business model. The company also recognizes the importance of supply chain relationships to support SSC development.

Company A adopts agile practice to optimize the production processes and the number of employees, so employees need to be multi-skilled and interchangeable. Agile practice is related to SSC development and operational and sustainability performance enhancement (Geyi et al. 2020). When equipped with agile practice, Industry 4.0 technologies, and CE practices, the company can optimize manufacturing costs with minimal disruption from the pandemic. The use of high-capability machines allows the company to meet a wide range of product requirements.

5.3 Distribution disruption

All the companies that participated in this study mostly distribute products by using in-house fleets, so the impact during the distribution phase can be easily controlled. In addition, all the companies are committed to serving mainly the domestic market, and hence their distribution is mainly affected by domestic disruption factors. During the

pandemic, Company A has designated product collection points for customers that enable contactless or minimal-contact transactions between employees and customers. Company B is focusing on the “Buy-back” project, in which the company buys products discarded by customers to close the supply chain loop. The company has its smelting facility which can turn end-of-life products into raw materials, enabling a CE ecosystem. However, it is still under the feasibility-study stage since the economically feasible ways to obtain those products back from customers still need to be further investigated. This project will promote the company's environmental sustainability performance and environmentally friendly reputation. Furthermore, Company B is entering the B2C market which increases the frequency of small-lot distributions. To handle the increased volume of small-lot deliveries, the company expects that the adoption of Industry 4.0 technologies at a wider scale is required to enable systematic tracking and optimize processes, resulting in an effective product distribution for end customers. Among all the companies, Company C is at the more mature stage of adopting Industry 4.0 technologies to manage the distribution processes, compared to the other two companies. The company has practical experience in the adoption of Industry 4.0 technologies for tracking and minimizing distribution costs.

5.4 Role of project management during the pandemic

Project management is an essential facilitator for Industry 4.0 technologies and CE practices adoption. COVID-19 pandemic has been identified as a catalyst for Industry 4.0 technologies adoption since the benefits obtained from these technologies could create new business opportunities and support the company's operations during the pandemic. For example, the pandemic makes Company B's management aware of the potential of Industry 4.0 technologies in improving its operations, and these technologies also reduce the impacts of disruption on the firm's operations. Industry 4.0 technologies also help promote the success of the product customization business model.

Company A notices that the success of CE practices and Industry 4.0 implementation relies on the highly-integrated nature of the company, requiring project management to create linkage between the organization, project leaders, team members, and products. The connection between Industry 4.0 technologies and the CE has been investigated by Dev et al. (2020), and it promotes information sharing in real-time which positively enhances economic and environmental performances. Company A also notices that the implementation of CE practices relies on effective coordination among

various parties, having project management as a supporting tool.

Company B sees that project management is a factor affecting business sustainability, where cost reduction is an incentive for utilizing project management. This aligns with the findings of Wang et al. (2017), highlighting that good resource management results in cost savings. Company B expects to attain the positive influence of project management in terms of sustainable development and successful Industry 4.0 technologies adoption on a wider scale. In the same manner, Company C notices that project management supports both Industry 4.0 technologies and CE practices adoption. The company views the support from top management as the key to initial project development. Good communication is also a necessary factor for Company C to effectively turn project plans into actions due to its large and complex organizational structure. Furthermore, project management helps manage resources, e.g., workforce, budgeting, and timeline, which are essential to reach the project goals.

In conclusion, project management and sustainable development are correlated for all the companies that participated in this study. For Company A, the successful adoption of Industry 4.0 technologies and CE practices requires proper project management to connect all project stakeholders. Similarly, Company B sees that the success of Industry 4.0 technologies and CE practices implementation relies heavily on effective project management. The company also notices that Industry 4.0 technologies can support CE practices which serve as the foundation for SSC development. Company C finds that project management helps the company in resource management for Industry 4.0 technologies adoption.

5.5 COVID-19: Moving from reactive to proactive

To react to the pandemic, Company A has already adopted CE practices to reduce manufacturing costs. Digital technologies also have the potential to reduce the required number of business processes. Furthermore, supply chain collaboration and supply chain relationships with upstream and downstream stakeholders directly help the company to solve problems quickly and reduce losses within the supply chain. Company B also notices the benefits of having good relationships with members within the supply chain. For example, the company generates its production plan according to the distributors' suggestions and is able to meet the demand during the pandemic period more accurately. Furthermore, the company's suppliers also recommend alternative consumables to reduce the costs. Company B has long-term relationships with both distributors and suppliers, and the company also collaborates with them. Both supply

chain relationship and collaboration are among SSCM practices (Mathivathanan et al. 2018). Company B highlights that Industry 4.0 technologies support a social-distancing working environment, and the COVID-19 disruption lowers technological adoption barriers, especially the lack of management commitment. Cloud technology has been adopted to manage the rapid increase in inventory levels, and simulation technology has been used to support product customization for customers. In the same manner, Company C uses Industry 4.0 technologies, e.g., cloud technology, IoT, Big data, and data analytics, to support employees to work from home during the pandemic. With the support of Industry 4.0 technologies, the company can analyze target customers and sales activities to improve profit margin. Company C also works closely with its suppliers and supports its customers to reduce the impacts of the pandemic.

To become proactive to the pandemic, Company A's management team mentions that they need to be active and alert and improve continuously. Customer requirements change quickly in a competitive environment, so the company must adapt to those changes to survive. To sustain the business, Company B has also started to move from a cost-competitive business model to the product customization business model that has a higher profit margin and is quality-oriented. The company aims to differentiate itself from competitors, and believes that Industry 4.0 technologies, the CE, and an SSCM can support this process. For Company C, to gain a competitive advantage over its competitors, the company develops engagement within the supply chain and creates a new business model. Industry 4.0 technologies help the company to enhance supply chain collaboration.

6 Discussion and conclusion

6.1 Theoretical implications

This section presents the contribution of the research based on our findings, linking the findings with related literature. From the RBV perspective, the previous study finds that many factors such as project management and management leadership have a positive influence on Industry 4.0 technologies implementation, and Industry 4.0 positively impacts sustainable production which eventually results in CE capabilities (Bag et al. 2021d). This is in line with our study as we notice that project management can support both Industry 4.0 technologies and CE practices adoption, and the support from the management level is crucial to the successful adoption of digital technologies. Moreover, recent studies have identified the mutually beneficial relationship between CE practices and Industry 4.0 technologies implementation since Industry 4.0 technologies can promote circularity of

materials and resources within the supply chain network (Kumar et al. 2021), help overcome SSC challenges (Yadav et al. 2020), and help achieve sustainable operations management (Lopes de Sousa Jabbour et al. 2018). Industry 4.0 technologies have been identified as the enablers and influencers of an SSC (Bag et al. 2021c). Institutional pressures are important factors to motivate digital technologies adoption, and these technologies contribute positively to the CE business model (Bag et al. 2021b).

Our study notices that the COVID-19 pandemic can motivate and accelerate firms to adopt digital technologies. The COVID-19 pandemic can be considered as the external driver for Industry 4.0 technologies adoption, and this study also finds that the pandemic reduces the resistance to organizational change. Moreover, the pandemic has an influence on management's perspective toward the need for digital technologies adoption. Firms tend to utilize the benefits obtained from both CE practices and Industry 4.0 technologies to reduce costs and minimize impacts from the disruption. Multi-tier supply chain collaboration is also necessary for firms to create an SSC. In line with previous literature (Lopes de Sousa Jabbour et al. 2018; Dantas et al. 2021), this study notices that CE practices and Industry 4.0 technologies promote sustainable development. The study of Mastos et al. (2021) demonstrates how Industry 4.0 technologies and the CE model help close the loop of the supply chain, resulting in reduced environmental and social impacts. Our study reveals that proper project management is required by firms to adopt Industry 4.0 technologies and CE practices successfully. Project management supports manufacturing companies to control costs, timelines, and resources. It also helps align organizational goals, top management direction, and employee mindset toward the successful adoption of both Industry 4.0 technologies and CE practices.

Previous studies focus on how Industry 4.0 technologies, the CE, and an SSC are related (Yadav et al. 2020; Mastos et al. 2021). This study extends the scope of the previous studies to cover the aspect of project management and impacts of the COVID-19 pandemic using the multiple case study approach in the Thai metals industry. The knowledge and linkage among these areas are identified. An SSC along with CE practices and Industry 4.0 technologies could help firms mitigate the impacts of disruption. Industry 4.0 technologies can improve supply chain competency (Chauhan et al. 2021). The relationship between sustainability and project management has been previously investigated (Martens and Carvalho 2016). The findings of this research notice that firms participated in this study have already used project management to support both Industry 4.0 technologies and CE practices implementation. Project management could support manufacturing firms to enhance business

sustainability by assisting them to effectively manage available resources.

This research expands the knowledge in this field by promoting an understanding of how project management supports Industry 4.0 technologies and CE practices adoption, linking these concepts with SSC development. This study also investigates the impact of the COVID-19 pandemic on the metals industry in Thailand, in terms of demand, production, and distribution. Our study provides more understanding of how companies react to the pandemic, reactively and proactively. Therefore, this study highlights the possibility of adopting Industry 4.0 technologies and CE practices with the support of project management to develop an SSC as the possible solution to the disruption.

6.2 Practical implications

The COVID-19 pandemic impedes the growth of business, posing significant negative effects on manufacturing companies' operations and their supply chains. This study finds that firms' ability to adapt and adjust to the dynamic situation caused by the pandemic is essential to their survival. The pandemic also expedites the Industry 4.0 technologies adoption since the adoption of these technologies creates new business opportunities and reduces the impacts of the pandemic. Customer behavior has been heavily affected by the pandemic, hampering the demand for some metal products. Focusing only on being cost-competitive might affect a firm's ability to survive. The agility of business operations such as a multi-skill workforce and flexibility of machines can help the company save costs. Moreover, with agile skills, companies can better respond to changes in customer requirements and better utilize available resources. Digital technologies support manufacturing firms to manage their supply chain operations, e.g., inventory management. The use of Industry 4.0 technologies increases firms' opportunities to enter new markets and help create new business models. However, the implementation of Industry 4.0 technologies normally requires high capital investment, and it can take time to fully implement these technologies. Thus, companies need to carefully consider the costs and benefits of implementing Industry 4.0 technologies.

Product customization tends to be one of the possible solutions, helping firms to attain more profit margins, better address customer needs during the pandemic, and differentiate from competitors. This study finds that companies try to make themselves different from their competitors to enter a new market with lower competition, by relying on product customization. Industry 4.0 technologies such as simulation, robotics, and automation help them to manufacture products according to customer specifications and support the product customization business model. For example,

during the pandemic, some customers especially in the construction sector face difficulty in terms of workforce availability, and they want to minimize the required number of working hours. In this regard, product customization, i.e., pre-fabrication and pre-assembly of steel structures, can support customers to reduce construction time. Moreover, IoT technology helps determine the bottleneck within the company and supply chain operations as well as accurately identify costs. It also improves supply chain visibility (Mastos et al. 2020). This in turn supports CE implementation and develops an SSC.

Project management is an essential element in promoting the success of Industry 4.0 technologies and CE practices adoption. It promotes organizational goal alignment, and manages and supports digital technologies integration with the company's operation. The study also finds that top management commitment and support are essential to driving the success of Industry 4.0 technologies and CE practices adoption. Moreover, this study notices that Industry 4.0 technologies and CE practices could be considered a source of sustainable competitive advantages and drivers of an SSC. Supply chain collaboration also provides benefits to manufacturing companies by creating new opportunities and supporting new business models, e.g., the product customization business model, to create sustainable development.

6.3 Conclusions

The impacts of the COVID-19 pandemic on operations of Thai metals manufacturing companies have been investigated in this study using the multiple case study, consisting of small-, medium-, and large-size companies. Both individual- and combined-case analyses have been performed to provide a detailed analysis of each company as well as compare among cases. Even though the contexts of these companies are different, this study notices the potential of project management, Industry 4.0 technologies, and the CE in contributing to SSC development. These companies prioritize moving toward lower competitive market environments, and they see product customization as one of the possible solutions. There are still difficulties in fully integrating Industry 4.0 technologies with current operations. The implementation of these technologies is restricted by main barriers including lack of knowledge and expertise, lack of management commitment, and high capital investment. Despite the implementation difficulties, the companies consider both Industry 4.0 technologies and the CE implementation as long-term solutions. This study also highlights how the companies that participated in the study handle and overcome the disruption, reactively and proactively. The outcomes of this study could be beneficial for the manufacturing sector, policymakers, and industrialists in

implementing Industry 4.0 technologies and the CE, developing an SSC, and dealing with disruptions, which help promote long-term sustainable development.

6.4 Research limitations and future studies

This study adopts the multiple case study approach in the Thai metals industry, covering the impacts of the pandemic and the concepts of project management, Industry 4.0 technologies, CE, and SSC. Future studies can expand the scope of this study to cover other manufacturing industries. A larger scale of study focusing on more case studies could strengthen the research by obtaining more input from various manufacturing companies in different industries. Conducting survey-based studies could also provide a larger picture and larger scale input, allowing future studies to compare different manufacturing industries. Since this research only focuses on manufacturing companies in Thailand, cases of manufacturing companies in other developing countries or developed countries might differ in terms of the success in Industry 4.0 technologies and CE practices implementation as well as SSC development. Hence, it is interesting to compare and investigate companies in countries with varying contexts in the future research.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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