Enhancing supply chain resilience and economic performance through Industry 4.0 and ESG integration: the mediating role of sustainable practices

Enhancing Supply Chain Resilience and Economic Performance through Industry 4.0 and ESG Integration: The Mediating Role of Sustainable Practices

Abstract

Purpose – The study aims to investigate the antecedents and outcomes of firms' supply chain resilience, focusing on technology and sustainability capabilities. The study examines Industry 4.0 and the firms' commitment to environmental, social, and governance (ESG) as key resources for reshaping supply chains. Sustainability capabilities such as circular economy and sustainable supply chain design are also investigated to analyse their impact on supply chain resilience. The study measures the effect of supply chain resilience on a firm's economic performance as its competitive advantage outcome.

Methodology/Design – The dynamic capabilities view and the information processing view are utilised as theoretical backgrounds. A partial least squares structural equation model is implemented to test the model using data gathered from 261 enterprises.

Findings – The results indicate that sustainable supply chain design and circular economy contribute to supply chain resilience, which in turn enhances a firm's economic performance. Our results also demonstrate that Industry 4.0 and firms' ESG commitment affect both sustainable supply chain design and the circular economy. Still, the contribution of ESG commitment to circular economy practices only exists through full mediation of sustainable supply chain design.

Originality – The study contributes to the operations and sustainable supply chain management literature by enhancing our understanding of the impact of Industry 4.0 and ESG commitment on sustainable supply chain practices, as well as the influence of these capabilities on enhancing supply chain resilience and environmental performance. In particular, the study reinforces the power of supply chain resilience as a dynamic capability that can help supply chains respond effectively to disruptions, thereby significantly improving economic performance by reducing overall operational and material costs, as well as energy consumption, while enhancing profitability and revenue.

Keywords – supply chain resilience, circular economy, sustainable supply chain design, Industry 4.0, ESG commitment, economic performance

1. Introduction

Ever-increasing disruptions caused by geopolitics and climate change compel supply chains (SCs) to prioritise resiliency. While pursuing resiliency, SCs need to be circular and sustainable to minimise their impact on climate change, i.e., by reducing emissions and waste. Although some scholars suggest a trade-off exists between sustainability and resilience (Rajesh, 2021), others argue that sustainability and

resilience can coexist (Fahimnia & Jabbarzadeh, 2016). Most recent papers suggest that sustainable SC management helps firms become resilient against disruptions (Eggert & Hartmann, 2023).

Circular practices and sustainable designing of SCs are innovative business processes in achieving resilience (Pieroni et al., 2019). Reshaping SCs into more circular and sustainable ones can be leveraged by recent innovative digitalisation, such as Industry 4.0 (I4.0) and blockchain, to enhance supply chain resilience (SCRES) (Nandi et al., 2021). The literature suggests that innovative digitalisation implementations in SCs, such as I4.0, positively contribute to SCRES (Tortorella et al., 2022). Innovative business models supported through technology can also help firms become resilient (Attah-Boakye et al., 2023).

Considering the role of sustainability in SCRES, circular economy (CE) practices and sustainable supply chain design (SSCD), supported by I4.0 technologies, are two innovative sustainable capabilities that can help SCs achieve resilience. However, while the literature underlines the role of circularity in achieving resilience, very few studies empirically examine this relationship (Kennedy & Linnenluecke, 2022). Sustainable and resilient SC design, on the other hand, is usually studied using modelling papers (i.e., Jabbarzadeh et al., 2019). Therefore, the impact of SSCD on SCRES requires investigation. Hence, the first question this study aims to address is whether sustainability capabilities affect SCRES.

RQ1: Do sustainability capabilities positively affect SCRES?

The impact of I4.0 on green practices is evident in the literature (Laskurain-Iturbe et al., 2021). While most papers suggest that I4.0 positively correlates with CE as a green capability, results might vary and offer different implications, considering the context of studies, such as the technologies considered (Rosa et al., 2020). Hence, more validation is required. Moreover, further research is also needed to understand if I4.0 affects other green capabilities of supply chains, such as SSCD (Ghobakhloo, 2020)

Technological resources are key to the green capabilities of SCs, yet reshaping SCs into more sustainable and circular ones also requires firms' commitment to environmental, social, and governance (ESG) implementations (Kumar et al., 2024). The firms' ESG commitment includes establishing a sustainable environmental policy or plan and investing in resources and employees for a socio-ecological transformation (Liu et al., 2024). These social structures help build responsive, innovative business models that include I4.0 and green practices to reshape the SCs in gaining performance (Bellamy et al., 2020). For instance, the review conducted by Ng et al. (2021) indicates that both ESG and I4.0 are essential for the sustainability of the global energy sector. However, the literature does not thoroughly investigate whether both I4.0 and ESG commitment affect circularity and SSCD when measured in the same model. Hence, the following research question needs to be addressed.

RQ2: Do I4.0 and ESG both positively affect circularity and sustainable supply chain design?

Several studies focus on identifying and assessing the sustainability capabilities as an antecedent to achieving resilience, and both contribute to improving economic

performance (EP) (Rajesh, 2021). Others argue that firms need to recalibrate various sustainability capabilities to achieve EP through strategic resilience stewardship (Luo et al., 2024). SCRES is considered a dynamic capability that can help SCs respond effectively to disruptions, thereby significantly improving EP, i.e., reducing overall operational and material costs, as well as energy consumption, while enhancing profitability and revenue (Kumar et al., 2024). Safari et al. (2024) found that SCRES can help improve firm performance. Their findings suggest that collaboration across the SCs with I4.0 and resilience as a capability can facilitate effective contingency planning and enhance performance. Although recent studies found a positive relationship between sustainable SC management and resilience, knowledge of this relationship is scant in the literature, particularly in empirical studies (Negri et al., 2021). Moreover, most studies in the literature measure the impact of resilience on the sustainability performance of SCs (i.e., Singh et al., 2023), whereas Eggert and Hartmann (2023) document that sustainable SC practices have helped firms become resilient against disruptions. This simultaneous endogenous and exogenous role of SCRES suggests that while some sustainability capabilities, such as environmental and social ones, can be antecedents of SCRES, sustainability performance indicators, like EP, can be positively influenced by SCRES. Therefore, given the I4.0 environment and sustainability capabilities, the third research question is as follows:

RQ3: Do SCRES positively affect the facilitation of EP?

Considering the endogenous and exogenous role of resilience in sustainability (environmental and economic) and the impact of I4.0 and ESG commitment on sustainable SC practices, this study aims to investigate the antecedents and outcomes of SCRES by focusing on technology and sustainability capabilities. The research aims to measure the impact of technology and sustainability-related capabilities on SCRES and test whether SCRES enhance economic sustainability. The paper adopts the dynamic capabilities view (DCV) and an information-processing view (IPV) to underpin relationships between measured constructs. DCV focuses on reconfiguring resources to operate and create a competitive advantage in dynamic environments. However, DCV is limited to showing the information flows and decision structures that enable reconfiguration. IPV fills this gap by emphasising how organisations minimise uncertainty through information mechanisms.

By integrating DCV and IPV, this study provides a holistic lens not only of the necessary capabilities for firms but also of how organisational information systems, routines and coordination mechanisms back these capabilities. DCV align well with our research, as I4.0 and ESG commitment are recognised as essential resources for developing sustainable dynamic capabilities, such as CE and SSCD. These capabilities are utilised to enhance resilience and improve performance. The IPV is also needed to underpin our research because it emphasises the role of data and knowledge flows, enabled by I4.0 technologies like IoT, blockchain, AI, e-commerce platforms (Alkaraan et al., 2022; Jabbar et al., 2024; Yadav & Mahara, 2019) and ESG commitment, in facilitating the complex interactions and decisions required for sustainable and resilient supply chains. The digitally enabled interfaces remain unexplored as resilience enablers, particularly through the ESG commitment and sustainability lens. Current research on sustainability, CE practices, and SCRES

primarily focuses on firms' structural, technological, and operational capabilities. There is seminal research on the analytical and cognitive dimensions of innovative decision-making models that could moderate the adoption of ESG principles and I4.0 technologies, thereby influencing the sustainability and resilience outcomes of firms.

Our study offers original contributions to the literature. Our results confirm that while the circular and sustainable practices of firms strengthen the SCRES, the SCRES, in turn, improve a firm's EP. This result validates the vital role of SCRES in sustainable business performance and highlights the reciprocal relationship between SCRES and sustainable business practices. Our study also examines the relationship between ESG commitment and CE practices, finding that ESG commitment can positively influence CE practices through the mediation of SSCD. The study also examines the role of I4.0 on CE practices and SSCD, and documents that the mediation of SSCD further enhances the positive effect of I4.0 on CE practices.

2. Literature review and theories

To reshape the SC for resilience, we underpinned DCV and IPV for the study.

2.1. Theoretical Foundations of Supply Chain Resilience

2.1.1 Dynamic Capability View (DCV)

Dynamic capabilities (DCs) are acknowledged as the sources of sustainable competitive advantage as they enable the creation of abilities to adapt to dynamic environments caused by disruptions, uncertainties and innovation (Ferreira et al., 2020; Teece & Pisano, 1997). DCs are the firms' ability to adapt to fast-paced environmental changes by integrating, building and reconfiguring internal and external capabilities (Teece & Pisano, 1997). As the foundation lies on the Resource-Based View (RBV), the Dynamic Capabilities View (DCV) helps organisations transition from static to dynamic/uncertain environments by transforming existing resources (Díaz-Chao et al., 2021). DCV proposes that firms should reconfigure their resources and capabilities to stay competitive, enabling organisations to adjust to uncertainty and address challenges. Teece et al. (1994) explained how internal and external competencies can be created, utilised and reconfigured to comply with changing business environments via the mobilisation of DCs.

Capabilities are unique to firms, and their performance depends on the existing criteria within each firm. The term 'dynamic' implies a varying environment due to changing market conditions and an increasing rate of innovation. At the same time, the 'capabilities' aspect focuses on 'sensing' opportunities and threats, 'seizing' opportunities and 'reconfiguring' resources (Teece, 2007). DCs offer a solid theoretical background for CE adoption and SSCD because the theory suggests that DCs enable firms to reorganise their business divisions and recombine resources to respond to environmental changes (Ambrosini & Bowman, 2009).

Research also supports that DCV offers an excellent background for studying a firm's ability to adopt CE (Khan et al., 2020; Scarpellini et al., 2020), SSCD (Kähkönen et al., 2023) and EP (Protogerou et al., 2011). For example, Raza et al. (2021) found that

sustainable supply management, as a DC, positively influences the company's sustainability performance, with supply chain risk management fully mediating this relationship. Bag et al. (2019) examined the role of dynamic remanufacturing capability in enhancing SCRES within the CE. They concluded that market, management, and technical factors positively impact dynamic remanufacturing capability, which subsequently has a beneficial effect on SCRES. Chari et al. (2021) demonstrated that DCs positively influence CE adoption and aid in building resilient supply chains. Additionally, I4.0 technologies contribute to improving DCs, which in turn promote circular and resilient supply chains. Lu et al. (2024) revealed that dynamic capabilities integrated from I4.0 technologies and CE help to achieve organisational sustainability and reduce waste.

2.1.2. Information Processing View (IPV)

The IPV proposes that a firm is an information processing system that tries to reduce uncertainty by collecting, processing, and leveraging information (Daft & Weick, 1984; Tushman & Nadler, 1978; Yan et al., 2023). Uncertainty is defined as the gap between the information required to execute a task and the information actually obtained by the firm (Galbraith, 1974). The main suggestion of IPV is that firms have different information processing needs and require different support mechanisms to meet these needs (Trautmann et al., 2009). IPV consists of three theoretical elements: information processing requirement, information processing capability, and fit between the information processing requirement and capability.

Uncertainties, which are environmental, task, and inter-organisational, shape the information processing requirements. The main reason for environmental uncertainty is instability resulting from scarce resources, while task uncertainty refers to the complexity of the task that needs to be executed (Melville & Ramirez, 2008). In other words, the more complicated the task, the greater the uncertainty (Tushman & Nadler, 1978). Moreover, the interplay between firms causes additional uncertainty (Premkumar et al., 2005). Firm structural design, coordination, control, and information technology affect information processing capabilities (Bensaou & Venkatraman, 1995). Achieving optimal firm performance and efficiency by fitting information processing requirements and capabilities also maintains a competitive advantage (Premkumar et al., 2005).

IPV can be used as a theoretical background while investigating the adoption of I4.0, CE principles and SSCD. The existing literature has explored the role of adopting CE principles and redesigning SCs as structural changes that create uncertainties, require information, and lead to changes in information processing to achieve SCRES. For example, Jain et al. (2024) demonstrated that I4.0 technologies improve SCRES by increasing supply chain visibility, with IPV providing a theoretical foundation to explain how digital capabilities help firms process information more effectively in dynamic environments. Bag et al. (2023) revealed that I4.0 technologies enhance sustainable supply chain operations via improving resource consumption rate and reducing waste and pollution. Birkel and Müller (2025) identified that I4.0 technologies impact SCRES by enhancing companies' SC risk management systems both directly and indirectly.

Complex SC operations are information-intensive, and as per IPV, EP depends on the firms' information processing capabilities (Belhadi et al., 2024). Earlier SC management literature has demonstrated that information processing capabilities such as AI, Big data, and blockchain, can help firms quickly collect, integrate and interpret complex SC data to improve EP (Karmaker et al., 2023; Sahoo & Upadhyay, 2024). IPV suggests that firms can respond to uncertainty by boosting information quality or their ability to process information (Fan et al., 2016). IPV can ensure access to a more comprehensive information source, which affects resource utilisation and arrangement. I4.0 technologies act as a critical tool and capability enabling firms to share and process environmental, social, and governance information among stakeholders to achieve SCRES and improve EP (Mishra et al., 2023). Hence, to achieve SCRES and to attain effective collaborative and integrative relationships, the SC stakeholders must transmit, capture, and analyse large amounts of ESG information. Building on these theoretical foundations, the following sections discuss how I4.0 technologies, sustainability practices and ESG commitments have been integrated to enhance SCRES and performance.

2.2. Integrative Practices for Sustainable and Resilient Supply Chains

2.2.1 Industry 4.0 and Circular Economy as Enablers of Resilience

Disruptions have become an immediate concern for businesses in light of recent geopolitical tensions, pandemics, natural disasters, and Brexit. SCRES is a concept that focuses on mitigating the negative consequences of disruptions, returning to the robust stage of operations, and improving the performance and competitiveness of the SC (Ivanov, 2021). SCRES enables competitive advantage via effective adapting, responding and recovering from disruptions (Yu et al., 2019). Organisational capabilities are repurposed with the innovative I4.0 technologies, making SCs more agile, sustainable and efficient in resource and information (environmental, social, and governance) sharing (Belhadi et al.,2022). Earlier studies have established that I4.0 and sustainability play an imperative role in achieving SCRES (Ramirez-Peña et al., 2020). However, achieving this synergy requires inter-organisational innovative business models for the timely exchange of information (Mourtzis et al., 2022). Warner & Wäger (2019) have emphasised the possession of I4.0-based DCs that enable firms to realign their resources with the speedy reconfiguration of SCs to achieve SCRES.

CE is a restorative and regenerative economic system that aims to reduce the loss of resources by designing out waste, keeping products and materials in circulation for as long as possible and keeping resource value as high as possible in consecutive use cycles (Köhler et al., 2022). Initial studies show that adopting CE principles positively affects the SCRES (Kennedy & Linnenluecke, 2022). The literature documents that the 4Rs of the CE (reduce, reuse, recycle and recover) enhance resilience in the SC against disruptions (Fisher et al., 2020). Creating circular flows for material and energy across the SC helps achieve resilience by reducing dependency on finite resources, decreasing waste, and enhancing resource productivity and diversity. Hence, CE principles and practices appear as a distinct organisational resource that not only helps reduce the environmental footprint of products across their lifecycle but also

contributes to building a more resilient and sustainable SC, reinforcing the capabilities discussed earlier (Sánchez-García et al., 2024).

2.2.2. ESG Practices and Sustainable Supply Chain Design

Various antecedents have been discussed in the earlier literature to analyse their impact on achieving SCRES. For example, Kumar et al. (2024) have analysed the moderating role of ESG compliance between I4.0 and green practices with green servitisation to enhance SC performance. Quayson et al. (2023) have developed a decision support tool by integrating ESG to enhance firms' sustainability performance. Mooneeapen et al. (2022) have identified the barriers and opportunities associated with adopting ESG to enhance firms' profitability and performance. ESG risk-aware firms can maximise the DCs of their innovative business models to achieve sustainable value creation (Jeong et al., 2023; Zioło et al., 2023)

Effective coordination and integration of SSCD with I4.0 is an attempt to merge the triple bottom line principle to help firms improve sustainable performance (Moreno-Camacho et al., 2023). Kumar et al. (2023) modelled SSCD using I4.0 to enhance efficiency and coordination across the SCs. The impact of I4.0 and associated technologies is explored by Veile et al. (2024). They have analysed the importance of I4.0 in effective collaboration and the design of SCs to meet sustainability goals. In this regard, firms applying I4.0 technologies complement their capabilities, leading to SSCD and a competitive advantage.

SSCD involves incorporating environmental and social measures into traditional, cost-focused SC management practices (Jabbarzadeh et al., 2018), while it also requires the active participation of suppliers, producers and distributors (Zeng et al., 2017). SSCD enables firms to reduce negative environmental impacts and improve social and economic benefits. It focuses on reducing resources, waste, and greenhouse gas emissions across the SC while combining the acquisition, transformation, and distribution processes of products and services (Sudarsan et al., 2010). SSCD decisions include a selection of clean energy sources for production processes, adopting environmentally friendly production technologies and product design, optimisation of logistics facilities at the location to reduce demand for logistics, selecting the efficient mode of transportation between logistics facilities, selecting dealers following the rules and regulations for environmental protection and optimising ways to recycle waste materials and spare parts (Centobelli et al., 2021). Building on the discussion of I4.0, CE, SSCD and ESG practices as key enablers, the following section delves deeper into the specific organisational, technological and strategic antecedents that support SCRES, highlighting how these practices translate into capabilities that firms can develop and operationalise.

2.3. Supply Chain Resilience Antecedents and Enablers

This section examines how organisational, technological, and strategic capabilities serve as antecedents of SCRES, with a particular focus on the role of Micro, Small, and Medium Enterprises (MSMEs) and firms in emerging economies.

2.3.1. Organisational, Technological and Strategic Capabilities Supporting SCRES

Understanding the antecedents that lead to SCRES is essential for companies seeking to develop resilient and financially efficient supply chains. This categorisation is crucial as it emphasises the various capabilities firms need to develop, ranging from technological tools to strategic mindsets. These antecedents mainly include dynamic capabilities, technological tools, and strategic approaches that together enable organisations to predict, react to, and recover from disruptions, building on the integrative practices described in the previous sections. DCs are especially important because they help firms identify opportunities and threats, capitalise on them effectively, and adapt resources as needed. In addition, technological advancements and strategic frameworks support these capabilities by strengthening a firm's resilience. Categorising these antecedents clarifies how different organisational skills and resources contribute to the overall resilience of the supply chain.

To ensure resilience in their SCs, organisations have been reshaping their SCs with various dynamic capabilities, including but not limited to collaboration (Scholten & Schilder, 2015), agility (Christopher & Peck, 2004), flexibility (Pettit et al., 2010), and social capital (Gölgeci & Kuivalainen, 2020). These capabilities enable firms to adapt quickly and recover effectively from disruption events. Technological capabilities such as the adoption of I4.0 tools, strengthen adaptive capacities by enabling rapid information exchange and process reconfiguration. Additionally, strategic orientations focused on environmental awareness and long-term sustainability contribute to building robust and resilient SC structures.

2.3.2. Antecedents in Emerging Economics and MSMEs

Sustainability and resilience have been studied in detail using various methodological approaches in the context of MSMEs (Table 1). MSMEs and firms in emerging economies are particularly important because they often face higher vulnerability to disruptions and have limited resources to build resilience. The studies reviewed collectively emphasise the wide range of strategies MSMEs utilise—such as digital transformation, technological adoption, innovation, and green practices—to foster resilience and improve sustainability. These methods are especially important in emerging economies, where firms are more vulnerable to disruptions and have fewer resources for capacity building. For instance, several quantitative studies (Muafi et al., 2025; Sharma & Sharma, 2023) illustrate how leadership, entrepreneurship, and the COVID-19 pandemic influence resilience outcomes.

Table 1. Earlier research empirical comparison on sustainability and resilience in MSMEs

Study	Purpose	Context
Satpathy *et al.* (2025)	A mixed-method approach is adopted to analyse digital tools, such as e-commerce and cloud computing, to examine green sustainable practices and achieve resilience in emerging economies.	MSME resilience and sustainability.
Muafi *et al.* (2025)	A quantitative method was applied to survey data from 286 MSMEs to analyse and moderate the role of digital leadership and entrepreneurship in enhancing sustainability and resilience.	Moderating role of digital leadership and Entrepreneurship in enhancing MSMEs resilience and sustainability.
Přívara *et al.* (2025)	Quantitative research design on structured survey data of 341 MSMEs was used to analyse the critical factors of digital transformation in achieving resilience and enhancing enterprise sustainability.	Digital Transformation factors in enhancing resilience and sustainability across MSMEs.
Sindhwani *et al.*(2023)	The multi-criteria decision-making (MCDM) approach, specifically MICMAC and TISM, was employed to identify the significant resilience enablers in MSMEs.	Significant resilience enablers in MSMEs.
Setyaningrum *et al.* (2025)	A quantitative research method was adopted based on survey responses from 400 MSMEs. Innovation and green creativity in decision-making were analysed for achieving sustainability and environmental performance.	Innovation and green creativity for achieving sustainability.
Sharma & Sharma, (2023)	Quantitative method was used on survey data from 225 MSMEs to analyse the impact of COVID-19 on MSMEs in India and analyse its impact on resilience and sustained growth.	Resilience and sustained growth in MSMEs.
Shareef *et al.* (2020)	A qualitative research method was adopted to conduct semi-structured interviews with supply chain stakeholders in MSMEs to analyse geographical, environmental, economic and cultural factors to achieve sustainability.	Geographical, environmental, economic and cultural factors to achieve sustainability.

Yadav & Mahara (2019)	Quantitative research method was adopted by using survey data from 163 firms to analyse technological adoption, such as e-commerce, in Handicraft MSMEs.	Technological adoption to improve performance
Yadav & Mahara (2018)	Survey data was collected from 163 MSMEs to analyse e-commerce adoption by organisational awareness and technological readiness.	Technological adoption.

Source: Authors own work

Primary research findings suggest a reciprocal relationship between SC sustainability and resilience, reinforcing each concept and generating synergies that enhance SC performance (Jabbarzadeh et al., 2018). Integrating these insights with broader SC literature underscores that combining sustainability and resilience can catalyse better organisational economics and competitive advantage (Mishra et al., 2023)**.** Moreover, digitalisation emerges as a critical enabler across both MSME-focused and larger SC contexts. Rashid et al. (2024) have analysed the role of information processing capability and digital SC in achieving SCRES, which will improve the performance of manufacturing firms. El Baz & Ruel (2024) have also concluded, based on their empirical analysis, that information processing capability with digitisation can positively influence SCRES and significantly enhance social SC performance.

2.4. Research Gap

Table 2 provides a summary of the key literature on improving SCRES through I4.0 and its main antecedents. While many studies have explored the role of I4.0 technologies in promoting resilience (Ivanoz, 2021; Ramirez-Pena et al., 2020; Riaz et al., 2024) and sustainability (Mourtzis et al., 2022; Pandey et al., 2025), our review highlights notable gaps in current research. Specifically, there is limited empirical data on ESG commitment within firms' sustainable practices. Although previous research has addressed elements like CE practices and SSCD, few studies have examined how ESG commitment interacts with these practices to strengthen SCRES and EP.

Moreover, earlier research has often treated these dimensions in isolation, failing to capture their interdependencies adequately. The potential mediating roles of SSCD and CE practices in achieving SCRES and EP remain underexplored. Our study addresses this gap by proposing a comprehensive framework that positions ESG commitment as a critical driver of CE practices, with SSCD acting as a mediating mechanism.

Our study emphasises the intersection of technological and sustainability resources and capabilities, highlighting the growing importance of I4.0, SSCD, and CE practices in achieving SCRES and EP. Surprisingly, no study has investigated the possibility of EP as a second-order capability. For instance, although CE and SSCD are believed to contribute to effectively measuring SCRES, earlier research has not documented whether SCRES directly improves EP. This capability reinforces the power of SCRES as a dynamic capability that enables SCs to respond effectively to disruptions, thereby significantly enhancing EP. Specifically, it reduces overall operational and material costs and energy consumption while improving profitability and revenue.

This integrated view distinguishes our work from existing studies, such as Yoşumaz & Uzun (2024), Pan et al. (2023), Tran et al. (2025), and Arimany et al. (2025), which have not fully explored the synergistic effects of these constructs. By establishing and empirically examining the link between ESG commitment and SSCD, this research provides a comprehensive understanding of how firms can develop resilient, high-performing supply chains through the strategic alignment of digital and sustainability initiatives, ultimately achieving EP.

Table 2. Existing literature and research gap

Studies	I4.0	ESG Commitment	SSCD	CE practices	SCRES	EP	Salient Points and Research Gap
Ivanov (2021)	✓		✓		✓		Authors have proposed various models to achieve resilience by integrating Industry 4.0, SSCD and CE practices. In this theme, we find the research gap that earlier studies have not simultaneously integrated Industry 4.0 and resilience with ESG commitment, SSCD, CE practices to achieve EP.
Belhadi *et al.* (2022)	✓		✓			✓	
Ramirez-Peña *et al.* (2020)	✓		*		✓		
Mourtzis *et al.* (2022)	✓		✓		✓		
Yoşumaz & Uzun (2024)	✓	✓		✓	✓		
Pan *et al.* (2023)	✓	✓		✓	✓		
Birkel & Müller (2025)	✓				✓		
Riaz *et al.* (2024)	✓				✓		
Pandey *et al.* (2025)	✓		*		✓		
Polimetla *et al.* (2025)	✓			✓	✓		
Jain *et al.* (2024)	✓			✓		*	
Ghobakhloo *et al.* (2025)	✓				✓		
Saha *et al.* (2025)	✓		*	✓	✓		Earlier researchers have considered various antecedents of SCRES, including Industry 4.0, ESG commitment, SSCD, and CE practices to achieve SCRES and eventually EP. In this theme, we identify a gap: although there is considerable research on achieving SCRES, there is a lack of seminal research that considers ESG commitment, SSCD, and CE practices simultaneously to achieve SCRES and EP.
Bhatnagar & Dixit (2025)	✓				✓		
Kudrenko *et al.* (2025)	✓		*	✓	✓		
Tran *et al.* (2025)		✓			✓	*	
Arimany Serrat *et al.* (2025)		✓	*	✓	✓	✓	
Sartzetaki *et al.* (2025)		✓		✓		✓	
Zheng *et al.* (2024)		✓			✓		
Piprani *et al.* (2024)			✓		✓		
Chan *et al.* (2024)			✓	✓	✓		
Rodrigues *et al.* 2025)	✓			✓	✓		
Le & Phi Tran (2025)				✓	✓	*	
Polimetla *et al.* (2025)	✓			✓	✓		
Ivanov *et al.* (2022)	✓			✓	✓		

Jabbarzadeh *et al.* (2018)		✓		✓		Earlier researchers have focused on Industry 4.0 to link sustainability and SCRES in order to achieve optimal performance. We identify a gap in the interplay between the linkages; hence, this study establishes the relationship between ESG commitment and sustainable practices, demonstrating that ESG commitment can positively affect CE practices through the mediation of SSCD.
Zeng *et al.* (2017)	*	*	✓		✓	
Sudarsan *et al.* (2010)	*	✓			*	
Piprani *et al.* (2024)	✓	✓		✓	*	
Benabdellah *et al.* (2024)	✓	✓		✓	*	
Reyes *et al.* (2024)	✓	✓		✓	*	
Chaouni Benabdellah *et al.* (2023)	✓	✓	✓	✓	✓	
Chatterjee *et al.* (2023)	✓	✓		✓	✓	
Agarwal *et al.* (2023)	✓	*		✓	*	
Frederico *et al.* (2023)	✓	*		✓	*	

Source: Authors own work

✓ for yes; * for some

3. Hypothesis development

3.1. I4.0, SSCD and CE Practices

I4.0 technologies complement firms' capabilities by providing connected information systems. These systems create inter-organisational linkage for efficient information sharing and collaboration across the SCs to meet businesses' environmental, social and economic standpoints (Li et al., 2020; Lopes De Sousa Jabbour et al., 2022). The Sustainable Development Goals (SDGs) recently pressured firms to adopt sustainability. In this context, the research on SC design focuses more on sustainability, which encompasses the ESG dimensions of sustainability (Tsolakis et al., 2021). Technologies are explored by Veile et al. (2024). They have analysed the importance of I4.0 in effective collaboration and the design of SCs to meet sustainability goals. In this regard, firms applying I4.0 technologies enhance their capabilities, leading to SSCD and competitive advantage. Therefore, in line with DCV and the above discussion, we hypothesise that:

H1: *I4.0 has a positive impact on SSCD.*

Several authors have focused on the applicability of technological innovation, i.e. with I4.0 and CE practices, in achieving sustainability (Junaid et al., 2024; Zhang et al., 2023). Lu et al. (2024) investigated the integration of CE and I4.0 to improve operational efficiency and sustainable performance. In this context, CE appears crucial in reducing waste generation and promoting sustainable practices to enhance the firms` EP (Hmamed et al., 2024). IoT is used to identify opportunities to minimise food waste and to improve preservation. For example, Iqbal & Kang (2024) developed an IoT-enabled preservation mechanism at the retail level to control water, recycling and material recovery. To achieve sustainability, they developed a CE mathematical model that incorporates IoT data from waste control, recycling, and material recovery. Bag et al. (2024) explored the role of big data and predictive analytics in analysing the technological impact on stakeholders by sharing information related to CE practices. The study's findings confirm that Big Data and predictive analytics enhance inter-organisational connectivity and increase stakeholder trust and engagement to achieve social sustainability. Sánchez-García et al. (2024) conducted a systematic literature review to improve the understanding of technological innovations, such as artificial intelligence and blockchain, to facilitate CE practices and develop new sustainable business models. Based on the above discussion, we postulate the following hypothesis:

H2: *I4.0 has a positive impact on the CE practices.*

3.2. Firms' ESG Commitment, SSCD and CE Practices

ESG is a critical indicator of sustainability for firms, demanding a shift in attention from financial/economic to broader social, cultural, and environmental management of resources (Alkaraan et al., 2022). The firms' commitment to ESG ratings has increased their sustainability performance (Matakanye et al., 2021). Hence, firms are adopting sustainable initiatives in their product design and lifecycle to protect the environment from harmful emissions (Ye et al., 2023). Rajesh and Rajendran (2020)

have empirically analysed a significant relationship between ESG ratings and sustainability. Many scholars have analysed firms' growing environmental and social pressure to adopt sustainability in their complex SC designs (Lucía Sabogal-De La Pava et al., 2021). The SSCD concept aims to integrate the triple bottom line principle in the SC design, encompassing sustainability's ESG dimensions (Moreno-Camacho et al., 2023). Gualandris et al. (2021) have empirically analysed the association between SC design/structures and ESG to achieve SC performance. Song et al. (2024) have analysed the ESG data from Bloomberg and concluded that firms with ESG commitments perform better in their SSCD and achieve superior sustainable performance. Thus, we see that the firms' ESG commitment is complementary to SSCD in achieving sustainability goals. Thus, we hypothesise that:

H3: *Firms' ESG Commitment has a positive impact on SSCD.*

Commitment to ESG drives firms to adopt CE practices such as reducing waste, maximising resource efficiency and recycling (Fatimah et al., 2023). The ESG social element steers firms to engage in community engagement activities, improve employees' working conditions, and promote employee equality (Bellamy et al., 2020). Liu et al. (2024) suggested that ESG commitment enables positive relationships with employees through fair labour practices and diversity and inclusion initiatives. When treated fairly, employees are more engaged in adopting the firm's sustainability goals. The inclusion of employees ensures they feel valuable to the company and provides a wide range of perspectives and ideas, leading to innovative solutions for sustainable practices and economic initiatives. ESG commitment whips firm reputations into shape. Furthermore, ESG establishes the basis of accurate reporting to stakeholders and ensures that managers and partners are accountable for business decisions (Bao et al., 2023). Thus, we hypothesise that a firm's ESG commitment affects the CE practices as follows:

H4: *Firms' ESG Commitment has a positive impact on the CE practices.*

3.3. SSCD, CE Practices and SCRES

The design of the SC is instrumental in achieving sustainable performance (Centobelli et al., 2021). SSCD encourages environmentally friendly product design while focusing on efficient resource utilisation, zero waste, and eliminating toxic substances (Zeng et al., 2017). Reducing waste in each stage of the SC (Sudarsan et al., 2010), which is one of the purposes of SSCD, is also an expected outcome of CE practices (Ellen Macarthur Foundation, 2015). Ageron et al. (2012) mentioned that adopting sustainable practices enforced by rules and regulations for environmental protection and implementing them when selecting SC stakeholders are instrumental aspects of SSCD. Adopting environmentally friendly technologies and clean energy sources in production aids firms in achieving resource efficiency and reducing waste (Zeng et al., 2017). For instance, Tesla's Gigafactory operates entirely on renewable energy sources, such as solar panels and wind turbines, which reduces its carbon footprint and waste (Tesla, 2023). Similarly, selecting efficient transport modes (Zeng et al., 2017) and optimising location selection to reduce transport needs (Pop et al., 2015) will lead to lower carbon emissions and transportation costs, supporting CE practices. Consequently, SSCD is instrumental in efficient resource utilisation, reducing waste,

and designing durable and recyclable products. For example, Nike amended its SC to adjust Flyknit technology, which enabled Nike to minimise material waste by 80% and transport needs (Knoernschild, 2022). Adopting SSCD aligns and amplifies the principles of CE; hence, we posit the following hypothesis:

H5: *SSCD has a positive impact on the CE practices.*

The SSCD concept attempts to merge the triple bottom line principle in the SC design, encompassing sustainability's ESG dimensions (Moreno-Camacho et al., 2023)**.** Integrating SSCD is a strategic decision to gain a competitive advantage and to achieve long-term resilience (Ivanov, 2018; Sabouhi et al., 2021)**.**

The SCRES largely depends on its design, as it defines how well the SC is designed to be resilient to sustain the disruption (Ivanov, 2024). The design of such an SC that is sustainable and resilient is a challenge for SC managers seeking to maintain the same sustainability under disruption (Mari et al., 2014). Numerous studies have shown a positive relationship between SSCD and SCRES (Jabbarzadeh et al., 2018; Sabouhi et al., 2021; Y. Wang et al., 2024)**.** Therefore, SCRES appears as another core dynamic capability from a DCV perspective that the effective SSCD can achieve. Thus, we hypothesise that:

H6: SSCD has a positive impact on SCRES.

Preliminary studies imply that implementing CE practices helps achieve SCRES (Fisher et al., 2020; Kennedy & Linnenluecke, 2022a; Sarkis, 2021). CE practices promote shifting from non-renewable to renewable raw materials, enabling resource independence and diversification, eventually contributing to more resilient SCs (Kennedy & Linnenluecke, 2022a; Wieland & Durach, 2021). Adapting new business models and implementing disruptive technologies will catalyse SCRES, as these optimisations will ensure continuous improvement, reduce waste, and restore operations affected by disruptions (Carraresi & Bröring, 2021). Dematerialisation, producing goods with fewer materials, will also contribute to achieving SCRES since it enables firms to reduce resource and material dependence, simplifies manufacturing processes, and helps execute contingency plans against disruptions (Gebhardt et al., 2022). Fisher et al. (2020) suggest that remanufacturing, reusing (Napoleone et al., 2022), and recycling (Yamamoto et al., 2022) will establish a basis for resilience in the SC against disruptions. Following the discussion above, the seventh hypothesis is proposed as:

H7: *CE practices have a positive impact on SCRES.*

3.4. SCRES and EP

SCRES can help SCs respond effectively to disruptions, which can significantly improve EP, i.e. reduction in overall operational and material costs and energy consumption while enhancing profitability and revenue (Kamble et al., 2020). Safari et al. (2024) found that SCRES can help improve firm performance. Their findings suggest that collaboration across the SCs and resilience as a capability can aid in effective contingency planning and performance improvement. Rashid et al. (2024) have analysed the role of information processing capability and digital SC in achieving

SCRES that could improve the performance of manufacturing firms. Firms cannot operate without developing SCR practices (Mishra et al., 2023). SCRES is imperative for the continuity of operations and performance in the presence of disruptions (Li et al., 2022). Hence, SCRES is a dynamic capability that helps SCs prevent, resist, and absorb disruption, thereby maintaining the continuity of the SC, which can significantly improve EP (Junaid et al., 2023). We, therefore, hypothesise that:

H8: SCRES has a positive impact on EP.

3.5 Mediating roles of CE practices and SSCD

While SSCD actions include choosing clean energy and environmentally friendly production technologies for production, optimisation of location and choosing efficient modes of transportation, following rules and regulations for the environment during stakeholder selection and recycling (Centobelli et al., 2021). These will enable firms to attain resource independence and diversification, waste minimisation, restore operations after disruptions and execute contingency plans (Dennehy et al., 2021; El Baz & Ruel, 2021). However, these practices might not be sufficient to ensure SCRES. The CE practices can act as a bridge between SSCD and SCRES since the SC design should be based on sustainability principles to mobilise CE practices. This ensures that CE practices are supported by network design, eventually enabling SCRES.

H9a: *CE Practices mediate between SSCD and SCRES.*

Although a positive relationship between ESG and CE practices is anticipated, empirical evidence directly linking ESG commitment to CE practices remains limited (Patil et al., 2023). ESG is confirmed to affect the sustainable performance of firms positively (Ye et al., 2023) and green innovation (Wang et al., 2023), yet it does not necessarily mean it can directly impact CE, which is a distinct sustainable practice. Circularity focuses on cycles of resources, such as reducing waste and using recycled materials. Environmental sustainability focuses on the broader environmental and climate impact, encompassing practices such as protecting nature and reducing carbon footprint. Given the extensive evidence in the literature demonstrating the positive effects of sustainable designs on CE and the influence of ESG on sustainability, it is hypothesised that SSCD can mediate the relationship between ESG commitment and CE practices.

H9b: SSCD mediates the relation between ESG commitment and CE practices.

Similar to ESG, SSCD can also play a mediating role between I4.0 and CE practices. The literature confirms the positive relationship between I4.0 and CE (Lei et al., 2023). Yet, the impact can be further increased, considering the literature also confirms the positive relation between I4.0 and sustainable SCs (Veile et al. (2024) and between sustainable SC and CE practices (Centobelli et al., 2021). Di Maria et al. (2022) suggest further investigation of the direct impact of I4.0 on CE practices. Their results show that the involvement of SC integration partially mediates the impact of I4.0 on CE practices. SSCD, such as environmentally friendly production and logistics, can increase the impact of I4.0 on CE practices, thus suggesting a mediating role of SSCD.

H9c: SSCD mediates the relationship between I4.0 and CE practices.

The hypothetical model for the study is illustrated in Figure 1. The model suggests that two theories, IPV and DCV, are integrated. Table 3 demonstrates how each construct in the model draws simultaneously on both theoretical lenses.

Table 3. Integration of DCV and IPV across constructs

Construct	DCV lens (resource reconfiguration)	IPV lens (information processing)	Integrated explanation
I4.0	Acts as a resource enabling the reconfiguration of technological resources to adapt SCs under disruption.	Enhances data visibility and coordination through IoT, AI, and cloud systems.	Contributes to resilience by creating new technological capabilities (DCV) and enabling information exchange (IPV)
ESG	Reflects an organisational resource that aligns and reconfigures internal resources and routines towards environmental, social and governance objectives.	Improves information transparency and stakeholder communication on sustainability issues.	Builds adaptive capacity by aligning sustainability objectives (DCV) with improved information disclosure and stakeholder communication (IPV)
SSCD	Reflects the capability to reconfigure processes, technologies and networks for sustainability and adaptability.	Enhances visibility, coordination and knowledge sharing across SC partners.	Utilises both technological resources (DCV) and cross-organisational information coordination (IPV) to allow firms to design SCs more sustainably
CE	Enables continual resource reconfiguration through reuse, recycling, and remanufacturing practices.	Relies on information exchange and traceability for closed-loop flows.	Links material circularity (DCV) with real-time information systems that support resource recovery (IPV)
SCRES	Higher order capability that reconfigures resources and capabilities to prepare, respond, absorb and recover from disruptions.	Facilitates sensing and responding to disruption-related information.	Emerges from the interplay of adaptive resource reconfiguration (DCV) and responsive information flow (IPV)
EP	Reflects outcomes of effective capability deployment	Results from improved decision quality and coordination.	Achieved through the combined effects of dynamic capability development (DCV) and information processing (IPV)

Source: Authors own work

4. Methodology

4.1. Sampling, data collection, profile of respondents

We have adopted a partial least squares structural equation modelling (PLS-SEM) to test relationships between SC reshaping resources and capabilities, SCRES, and EP. The survey data is collected from SC managers of industrial enterprises in Türkiye (previously known as Turkey). Türkiye is selected because the businesses in the country have well-established trade activities with and are connected to SCs of main industrial and trade regions such as the EU, UK, and the US (Balci & Ali, 2024). Also, most global companies have manufacturing facilities and are among the top businesses in Türkiye, such as Ford, Hyundai, JTI, Unilever, and Coca-Cola. Another motivation for conducting the survey in Türkiye is that it is a developing country, and the literature needs more empirical analysis of SCRES in developing countries (Aman & Seuring, 2023).

We conducted an online survey consisting of two parts, namely demographics and measurement questions. A total of six experts, with at least ten years of experience, including two academics and four SC managers, reviewed and confirmed the appropriateness of survey items. One of the academics is a professor in operations management, while the other is an associate professor in operations management. Two managers work in the automotive sector in production and operations roles, one manager works as a general manager in food and beverages, and one manager works as a procurement manager in the textile and fashion sector. All four managers have at least a bachelor's degree.

The survey is collected from the population of Türkiye’s top 1,000 industrial enterprises (Istanbul Chamber of Industry, 2024). Our study focuses on this specific, well-defined population rather than a random or representative sample of all firms in Türkiye. The top 1,000 companies are targeted as the population of our study because our survey includes advanced levels of SC, technology, and sustainability dimensions such as circularity, ESG, resilience, and I4.0 adoption. Managers in the top 1,000 companies are deemed more appropriate to respond to such questions due to more established SCs in their firms. The survey is answered only by SC, logistics, procurement, and top managers, who are more likely to understand concepts well. Responses from people with three or fewer years of experience are deleted. A total of 261 responses, equivalent to a 26% response rate, were collected.

Figure 1. Hypothetical model

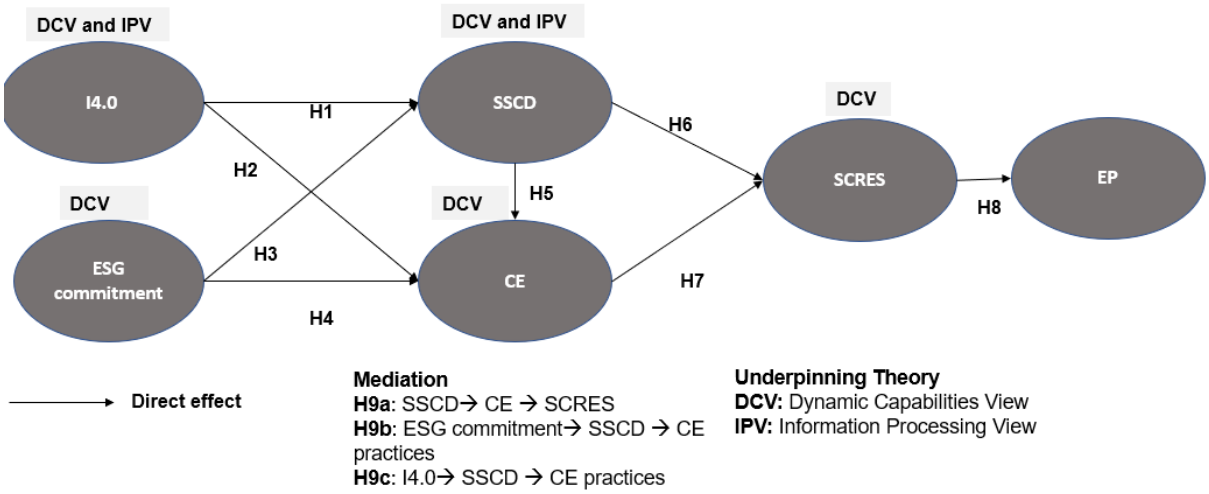


Table 4 illustrates the demographics and firmographics of respondents. Respondents in the survey are experienced, with over 60% having 11 or more years of experience, and 26% having between 7-10 years. They hold managerial positions either in top management as CEOs, directors, or regional managers, or in SC departments such as procurement, operations, and logistics. The respondents also represent various industries, with food and beverage, textile and fashion, and automotive having a larger share, which reflects the industrial distribution of the Top 1,000 list.

Table 4. Demographics and firmographics of respondents

Profile	Frequency	Percentage %
Age		
25-34	43	16.5
35-44	87	33.3
45-54	100	38.3
55 and more	31	11.9
Experience in the industry		
4-6 years	35	13.4
7-10 years	68	26.1
11-14 years	98	37.5
15 years and more	60	23.0
Department in the organisation		
Top management *	72	27.6
Logistics	53	20.3
Production, planning and operations	78	29.9
Procurement	58	22.2
Industry		
Food and beverage	69	26.4
Textile and fashion	47	18.0
Automotive	28	10.7
Machinery and industrial equipment	25	9.6
Home appliances and electronics	22	8.4

Paper	15	5.7
Steel and other metals	16	6.1
Chemicals	14	5.4
Plastics	8	3.1
Minerals extraction	14	5.4
Others	3	1.1

* Not part of a specific department, such as CEOs, regional managers, and founders.

4.2. Measurement development

Measurement constructs of the survey are adopted from the relevant and reliable literature. I4.0 construct items are adopted from Belhadi et al. (2022) and Sharma et al. (2023). I4.0's items include using relevant technologies in SC operations and utilising I4.0 in visibility, data analysis, and connectedness. The three-item approach of Kumar et al. (2024) is adopted for the ESG construct. The last item, i.e., ESG measurement, is modified based on Puriwat & Tripopsakul's (2023) content as it fits the context more. To prevent ambiguity, we have further explained these items in parentheses, which are shown in the Appendix. CE items are adopted from Lopes De Sousa Jabbour et al. (2023) as they represent three main dimensions of circularity: reduce, reuse, and recycle. SCRES items are adopted from Dennehy et al. (2021) and El Baz & Ruel (2021) to reflect preparedness, responding, and recovering stages of resilience. EP indicators, showing profitability, sales growth, and market share, are adopted from Khan et al. (2023).

4.3. Common Method Bias

Our survey asks both independent and dependent variables, as demonstrated in the Appendix, in the same survey, in which case common method bias (CMB) may exist (Kock et al., 2021). CMB issue may originate from respondent-related, i.e., lack of experience and lack of interest, and measurement-related sources, i.e., item complexity, scale formats and item order in the survey (Kock et al., 2021). We implemented several procedural and statistical measures to prevent CMB and ensure it does not exist in our research. As procedural measures, we made sure respondents are capable of and willing to provide answers to survey questions to avoid CMB (MacKenzie & Podsakoff, 2012) in several ways. First, we targeted the right respondents with sufficient experience and from relevant SC departments. This helps reduce the likelihood of bias due to uninformed or generalised responses, as right respondents with relevant experience are more likely to provide accurate and reflective input based on direct experience. Second, we communicated anonymity and the academic purpose of the research with respondents to ensure they were not worried about confidentiality issues. This procedural control is known to minimise socially desirable responding or strategic answering (Kock et al., 2021). Third, we communicated the importance of their response in understanding a key topic in the SC domain, thereby increasing their interest. This helps enhance respondent motivation and attention, reducing careless or random responding.

Following the recommendations of Kock et al. (2021), scale anchoring of construct items is designed differently as another procedural measure. For instance, we used very low – very high for ESG commitment, much worse – much better for EP and totally agree – totally disagree for the remaining measurement constructs. This variation in response formats helps reduce respondents' tendency to respond uniformly across items. In addition, we also positioned dependent and independent variables distant from each other for the proximity separation method. Regarding statistical methods, Harman's (1967) single-factor test was implemented to ensure that the first factor explained less than 50% of the total variance. In addition, following the recommendation of Kock et al. (2021) for the PLS-SEM method, inner variance inflation factors (VIF) are assessed. Accordingly, VIF values in the model change between 1.000 and 2.057, which are lower than the suggested maximum threshold of 3.3. Harman's test and VIF multicollinearity assessments suggest it is unlikely that the model suffers from CMB.

4.4. Data Analysis and Results

The conceptual model is tested by implementing PLS-SEM, the variance-based structural equation modelling. The PLS-SEM approach is selected because it is considered ideal when the purpose of the study is to explain and predict relationships between endogenous and exogenous variables, instead of theory testing and confirmation (Hair et al., 2018). Compared to CB-SEM, which is more appropriate for theory confirmation and requires strict assumptions such as multivariate normality and larger sample sizes, PLS-SEM is more flexible and suitable for prediction-oriented studies like ours (Hair et al., 2019). Our study utilises IPV and DCV as a theoretical background and does not aim to confirm them. El Baz Ruel (2021) also suggests using PLS-SEM in SC risk management and resilience studies, as the theoretical underpinning is still developing. Instead of CB-SEM, which focuses on model fit and theory testing, we chose PLS-SEM due to the exploratory nature of our model. PLS-SEM is also suggested when the complex model has multiple relations (Reinartz et al., 2009). Our model presents conceptual and contextual complexity as it integrates nine hypotheses across six constructs informed by two theoretical perspectives (IPV and DCV) and covers diverse domains such as technology (I4.0), sustainability (ESG and CE), and SCRES. This type of complexity also supports the use of PLS-SEM. SmartPLS4 is used to analyse the data.

4.4.1. Measurement model analysis

The measurement model is examined through several reliability and validity assessments. As seen in Table 5, all standardised factor loadings (SFL) are above the minimum suggested threshold of 0.708 and statistically significant ($P<0.001$) (Hair et al., 2019). Cronbach's alpha and composite reliability scores are also above the threshold minimum value of 0.7, confirming internal consistency (Bagozzi & Yi, 2012). Convergent validity is checked through average variance extracted (AVE) values. AVE values in our measurement model are above 0.50; the minimum required value (Hair et al., 2019).

Table 5. Reliability and validity scores of the measurement model

	Cronbach's alpha	Composite reliability	AVE	SFL *	Number of items
CE practices	0.859	0.859	0.639	0.774 - 0.818	5
ESG commitment	0.805	0.815	0.719	0.813 - 0.877	3
EP	0.890	0.892	0.820	0.896 - 0.918	3
I40	0.873	0.878	0.725	0.837-0.890	4
SCRES	0.926	0.928	0.694	0.793 - 0.870	7
SSCD	0.925	0.927	0.690	0.815 - 0.845	7

*SFLs of each construct are significant P<0.001

For discriminant validity, (Fornell & Larcker, 1981)'s recommendation is followed. Accordingly, the squared root of AVE values in the model should be higher than the correlations with other constructs. Table 6 confirms the discriminant validity based on the Fornell and Larcker method. We also conducted a heterotrait–monotrait ratio of the correlations (HTMT) to assess discriminant validity. All ratios are lower than the suggested 0.85 in our measurement model (Hair et al., 2018). Both HTMT and Fornell & Larcker methods provide evidence for discriminant validity in our model.

Table 6. Fornell and Larcker discriminant validity assessment

	CE practices	ESG commitment	EP	I40	SCRES
CE practices	**0.799**				
ESG commitment	0.576	**0.848**			
EP	0.585	0.546	**0.906**		
I40	0.703	0.579	0.563	**0.851**	
SCRES	0.61	0.631	0.591	0.718	**0.833**
SSCD	0.645	0.657	0.61	0.614	0.624

4.4.2. Structural Model Analysis

In our model, we implemented bootstrapping with 5,000 sub-samples to test path relationships – hypotheses. Results demonstrate (see Table 7) that all direct path relationships, except the one from ESG commitment to CE practices, are statistically significant and positive. Accordingly, all hypotheses, except H4, are accepted. I4.0 positively affects SSCD and CE practices, confirming H1 and H2 (H1: β=0.352, $P < 0.001$, H2: β=0.457, $P < 0.001$). ESG commitment has a positive and direct impact on SSCD (H3: $\beta = 0.453$, $P < 0.001$), but does not have a direct significant impact on CE practices (H4: $\beta = 0.127$, $P > 0.1$). Both SSCD and CE practices have shown a positive correlation with SCRES (H6: $\beta = 0.394$, $P < 0.001$; H7: $\beta = 0.356$, $P < 0.001$), while SSCD also has a positive effect on CE practices (H5: $\beta = 0.281$, $P < 0.001$). Finally, SCRES positively correlates with EP (H8: β=0.591, $P < 0.001$).

Hypothesis 9a suggests that CE practices play a mediating role between SSCD and SCRES. The examination of Figure 2 indicates that CE practices. A partial mediation

relationship exists between SSCD and SCRES. The indirect relationship between SSCD and SCRES is tested and found statistically significant (H9: β=0.100, P < 0.001). However, since the direct impact of SSCD on SCRES is also positive, CE plays a partial mediating role. Due to this mediation relationship, the total impact of SSCD on SCRES is increased from 0.394 to 0.494.

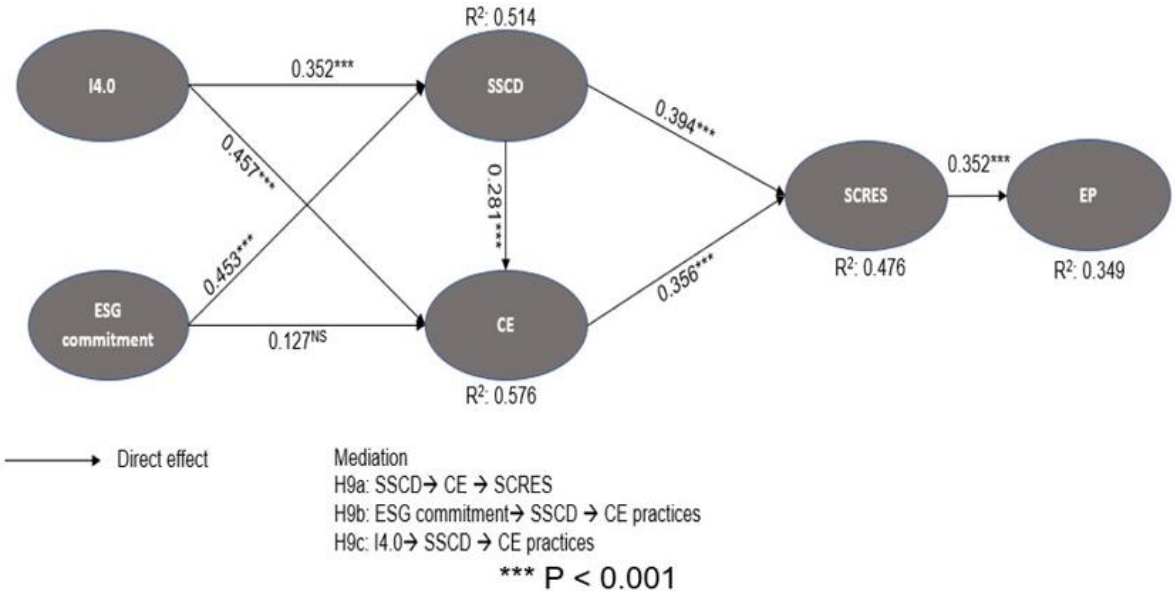
H9b and H9c suggest a mediating role of SSCD between ESG commitment and CE practices and between I4.0 and CE practices. Examination of Figure 2 indicates a full mediation between ESG commitment and CE practices and a partial mediation between I4.0 and CE practices. These mediation relations are tested through bootstrapping and found statistically significant (H9b: β=0.128, P < 0.01; H9c: β=0.099, P < 0.01). These results suggest that although ESG commitment does not directly impact CE practices, it has a statistically significant indirect effect on CE practices through the mediating role of SSCD. Results also suggest that the impact of I4.0 on CE practices can be increased through SSCD.

Table 7. Structural Path Relationships

Path relations	β	p-value	T value	Hypothesis
I4.0→ SSCD (H1)	0.352	0.000	5.140	Accepted
I4.0→ CE practices (H2)	0.457	0.000	7.132	Accepted
ESG commitment→ SSCD(H3)	0.453	0.000	7.136	Accepted
ESG commitment→ CE practices (H4)	0.127	0.113	1.586	Rejected
SSCD→ CE practices (H5)	0.281	0.000	3.502	Accepted
SSCD→ SCRES (H6)	0.394	0.000	4.954	Accepted
CE practices →SCRES (H7)	0.356	0.000	4.367	Accepted
SCRES→EP (H8)	0.591	0.000	11.642	Accepted
SSCD→CE practices →SCRES (H9a)	0.100	0.000	3.584	Accepted (Partial)
ESG commitment → SSCD → CE practices (H9b)	0.128	0.003	2.991	Accepted (Full)
I4.0 → SSCD → CE practices (H9c)	0.099	0.007	2.681	Accepted (Partial)

The coefficient determination (R^2) of dependent constructs is also tested to assess the predictive accuracy of the structural model (Nitzl, 2016). Figure 2 illustrates R2 values of each dependent construct in circles. Results suggest that CE practices, SSCD, SCRES, and EP have satisfactory explanatory power, as R^2 values as low as 0.1 can be considered satisfactory depending on the context (Hair et al., 2019). Our SCRES construct, for instance, has moderate explanatory power (R^2: 0.463, p<0.001) and is above some of the previously reported resilience constructs in SC studies, i.e., higher than Sturm et al. (2023)'s model that resilience has R^2 value of 0.348.

Figure 2. Structural Model Analysis and Path Relations



5. Discussion and implications

5.1. Discussion

This study fills the gap in the existing literature by examining the endogenous and exogenous role of resilience in sustainability (environmental and economic), the impact of I4.0 and ESG commitment on sustainable SC practices in achieving EP. Using empirical data, we have measured the impact of technology and sustainability-related capabilities on SCRES and tested whether SCRES has a positive effect on EP using DCV and IPV lenses.

The results confirm that I4.0 positively correlates with SSCD and CE practices. This finding is consistent with existing literature, suggesting that Industry 4.0 technologies complement firms' capabilities by providing connected information systems. These systems create inter-organisational linkage for efficient information sharing and collaboration across the SCs to meet businesses' environmental, social and economic standpoints (Li et al., 2020; Lopes De Sousa Jabbour et al., 2022). I4.0 can be utilised to design SSCD (Moreno-Comacho et al., 2023; Kumar et al., 2023; Veile et al., 2024) and adopt CE practices (Hmamed et al., 2023; Bag et al., 2024). These results empirically validate that I4.0 technologies complement organisational capabilities (such as SSCD and CE practices), making SCs more agile, flexible, and sustainable to gain a competitive advantage. The same has been echoed in Veile et al.'s (2024) study, I4.0 can facilitate organised interconnections and could transform SCs into agile and responsive entities. In line with IPV, I4.0 technologies create inter-organisational linkages for efficient information sharing in the design of SCs to meet businesses' environmental, social, and economic standpoints (Junaid et al., 2024).

ESG is a critical indicator of sustainability for firms that demands a shift in attention from financial/economic to broader social, cultural and environmental management of resources (Alkaraan et al., 2022). Many scholars have analysed firms' growing environmental and social pressure to adopt sustainability in their complex SC designs (Lucía Sabogal-De La Pava et al., 2021). The firms' commitment to ESG ratings has

increased their sustainability performance (Matakanye et al., 2021). Hence, firms are adopting sustainable initiatives in their product design and lifecycle to protect the environment from harmful emissions (Ye et al., 2023). The firm's adoption of the SSCD concept attempts to merge the triple bottom line principle in the SC design, encompassing sustainability's ESG dimensions (Moreno-Camacho et al., 2023). Our results confirm that firms with ESG commitments perform better in analysing environmental and social pressures and adopt SSCD in their complex SC design to achieve superior sustainable performance.

The literature indicates that ESG commitment aids firms in performing better at CE practices (Fatimah et al., 2023; Patil et al., 2023). However, our results revealed that ESG commitment does not directly impact CE practice. Several reasons may contribute to this outcome. First, misalignment between high-level ESG factors and strategic CE practices can cause issues. ESG commitments are often broad and general, whereas CE practices require focus on specific strategies such as reuse, recycling, or remanufacturing. The second reason could be the time horizon: ESG initiatives tend to pursue short-term goals to satisfy stakeholders, while CE practices involve long-term planning and investments. Third, ESG commitments can be fulfilled without fully integrating the supply chain, whereas CE practices require comprehensive collaboration and integration across the entire supply chain.

Our results demonstrate that SSCD factors can mobilise CE practices. SSCD practices, including the utilisation of clean energy in production, the selection of environmentally friendly production technologies, and product design, as well as transport modes and location, can directly impact CE practices. CE focuses on eliminating waste and pollution, promoting circular products and materials, and regenerating nature (Ellen MacArthur Foundation, 2015). In their study, Zeng et al. (2017) also found similar results, revealing that SSCD has a positive impact on CE capabilities. SSCD reduces resource consumption and waste materials via optimisation, which aligns with CE's goal of reducing raw material consumption and producing less waste.

Our study's findings confirm that firms that integrate SSCD perform better under disruption and are more resilient, which is also supported by earlier studies. Ivanov (2018) noted that applying SSCD for strategic decisions assists firms in gaining a competitive edge and ensuring long-term resilience. SCRES primarily relies on SC design, which determines how effectively the supply chain is structured to withstand disruptions.

Implementing CE practices helps achieve SCRES (Fisher et al., 2020; Kennedy & Linnenluecke, 2022a). CE practices promote shifting from non-renewable to renewable raw materials, enabling resource independence and diversification, eventually contributing to more resilient SCs (Wieland & Durach, 2021). The findings of our study confirm that the firms that implement CE practices are the ones that reduce resource and material dependence and contribute to achieving SCRES, which eventually help execute contingency plans against disruptions (Gebhardt et al., 2022).

Our results also suggest that CE partially mediates the positive impact of SSCD on SCRES. This result is significant because it indicates that circular practices, such as

waste reduction and reusing, can further increase the impact of sustainable design of SCs on achieving resilience. Our findings confirm that SSCD has a positive effect on SCRES. This makes a unique contribution to this study, where sustainability capabilities, i.e., environmental and social ones, are antecedents of SCRES aimed at avoiding disruptions. This finding is limited to earlier empirical studies in building an innovative business model to achieve SCRES. Furthermore, our results empirically confirm the preliminary studies, which state that implementing CE practices contributes to achieving SCRES (Fisher et al., 2020; Kennedy & Linnenluecke, 2022). DCs, such as CE practices, aid in achieving SCRES by ensuring a predictable raw material supply (Sarkis, 2021), diversifying virgin raw materials (Kennedy & Linnenluecke, 2022), and enhancing product design (Carraresi & Bröring, 2021).

Our findings suggest that adopting SSCD mediates the indirect relationship between ESG commitment and CE practices. To the best of our knowledge, there is limited empirical research examining the mediating factors of SSCD in the context of sustainability. The results propose that SSCD serves as an underlying mechanism to explain the relationship between ESG commitment and CE practices. The findings reveal that the effectiveness of ESG commitment should be achieved through the establishment of SSCD. SSCD integrates resource efficiency and waste reduction into the SC to guarantee that ESG goals and CE objectives align. In addition, ESG commitments are translated into practical measures that support CE practices through SSCD, such as integrating recycled materials and designing products for easier disassembly.

Our findings provide evidence of the crucial role of SSCD in mediating the relationship between Industry 4.0 and the adoption of CE practices. The implementation of SSCD practices, such as optimising production to reduce waste, utilising spare parts, and employing environmentally friendly production technologies, which is enhanced by I4.0 technologies, can boost the implementation of CE practices. The results of our study confirm that ESG commitment fosters SSCD. Building on the DCV, DCs such as SSCD (Ambrosini & Bowman, 2009) and CE practices (Chari et al., 2021) enable businesses to reorganise their business divisions and recombine resources to respond to environmental changes.

Furthermore, the study indicates that sustainability performance indicators, such as EP, are positively affected by SCRES. Our findings reinforce the power of SCRES as a DC that can help SCs respond effectively to disruptions, which can significantly improve EP, i.e. reduction in overall operational and material costs and energy consumption while enhancing profitability and revenue. Organisations cannot operate without developing SCRES as a capability (Mishra et al., 2023). Li et al. (2022) also claimed that SCRES is imperative for the continuity of operations and performance in the presence of disruptions.

5.2. Theoretical implications

The study contributes to the operations and sustainable SC management literature by increasing our understanding of the impact of I4.0 and ESG on sustainable SC practices and the influence of these capabilities on enhancing SCRES and EP.

Conceptually, this research on reshaping SCs into more circular and sustainable ones to achieve SCRES is a significant shift from earlier research (Kumar et al., 2024, Nandi et al., 2021; Tortorella et al., 2022), which does not thoroughly investigate whether both I4.0 and ESG affect circularity and SSCD when measured in the same model. This research has several theoretical implications for reshaping the SCs to achieve SCRES.

First, the study utilises DCV and IPV as the model's underpinning theories, demonstrating their complementary role in studying complex SC models that assess technological and sustainability dimensions. This study is among the early attempts to integrate DCV and IPV, offering a comprehensive perspective on the capabilities firms require and how organisational information systems and coordination structures must support these capabilities in the dynamic environment in which SCs operate. Such a dynamic environment requires interdisciplinary and multidimensional concepts, which often compel the integration of multiple theories.

Second, we contribute to the literature by empirically analysing the technology and sustainability-related capabilities (such as I4.O, SSCD and CE practices) as antecedents to SCRES, which organisations align into their innovative business processes to redesign the sustainable SCs in case of disruption and recover to build resilience. Moreover, our study demonstrates that SCRES can boost a firm’s EP. This result contributes to the literature by highlighting the reciprocal relationship between SCRES and sustainable business performance.

Third, this study developed a conceptual model to investigate the mediating role of CE practices between SSCD and SCRES, as well as the mediating role of SSCD between I4.0 and CE practices and between ESG commitment and CE practices. Partial and full mediations in the model indicate that SSCD and CE practices can play a mediating role for each other between resources, such as I4.0, performance outcomes, and resilience. While ESG commitment does not directly affect CE practices, the full mediating role of SSCD establishes a meaningful relationship between ESG commitment and CE practices. Although ESG commitments are seen as broad and general, tending to pursue short-term goals and not requiring full integration into the supply chains, CE practices focus on specific strategies, require long-term planning, and necessitate comprehensive collaboration. Our study demonstrates that SSCD can mobilise ESG commitment towards CE practices. The full mediating role of SSCD between ESG commitment and CE practices highlights the need for innovative sustainability approaches.

Fourth, the study contributes to the broader sustainable SC literature by providing evidence of a positive relationship between firms’ ESG commitment and effective SSCD. Thus, our study emphasises the importance of incorporating sustainability indicators into the design of SCs, such as greenhouse gas emissions, resource consumption, and social well-being, to better prepare for meeting the UN's sustainability goals. Finally, this study adds to the research stream by showing SCRES as a dynamic information processing that helps SCs prevent, resist, and absorb disruption and maintain the continuity of the SC, which can significantly improve EP (Junaid et al., 2023).

Lastly, beyond examining individual relationships, this study offers a holistic evaluation of how technological and sustainability-oriented resources are channelled through sustainable supply chain design and circular economy practices to influence resilience and performance outcomes. By simultaneously examining how technological (Industry 4.0) and sustainability-oriented (ESG) resources contribute to dynamic capabilities (SSCD and CE) that, in turn, enhance SCRES and EP, this research provides a comprehensive view of capability interlinkages in achieving sustainable resilience.

5.3. Managerial and Policy Implications

In the complex disruptions and rising ESG expectations, this study's findings offer several implications for managers by exploiting technological interventions and sustainable SC practices to build SCRES and achieve EP. Firstly, the UN Sustainable Development Goals (SDGs) pressured firms to adopt sustainability to address environmental challenges. Therefore, managers must design innovative business models to develop sustainability, sense disruptions, and build SCRES. They need to invest in technology (I4.0) and sustainability capabilities (SSCD, CE) to collaborate effectively across the SCs.

According to the findings, managers are advised to promote anticipation of these sustainability capabilities that will help firms build SCRES. Secondly, the study's findings indicate that adopting technologies such as e-commerce, artificial intelligence, machine learning, big data analytics, and cloud computing, along with sustainability capabilities, plays a crucial role in enhancing relationships with sustainability and SCRES. Alone, technology and sustainability capabilities will not ensure SCRES and EP. The combination of a skilled workforce with training and development programs will create competence to sustain competitive pressure and achieve EP.

Thirdly, our findings indicate that SSCD fully mediates the relationship between ESG commitment and CE practices. Therefore, the firm needs to have ESG commitments, such as enforcing economic, environmental and social dimensions in their SC design, as it reduces waste across the product lifecycle and protects the environment from harmful emissions. Fourthly, it is anticipated that managers should consider the factors associated with technology adoption, training, and entrepreneurship curriculum to equip MSMEs with the knowledge, skills, and mindset necessary for achieving broader sustainability and resilience goals. Overall, the study reveals that technology and sustainability capabilities are crucial in building SCRES, as ESG commitment enhances relationships and promotes green innovation to reduce waste. Based on the findings, we have developed a RISC framework (Table 8) for practitioners that can be implemented to address SCRES effectively and achieve EP. However, organisations face a few implementation challenges in adopting the RISC framework, including high upfront costs for technology and ESG transformation, data silos across IT and operational sustainability teams, regulatory complexities in various countries, supplier resistance, and capability gaps in MSMEs.

Table 8: RISC Framework

Steps	Focus Area	Key Actions to Practitioners

Response	Identification of vulnerabilities in the SCs	Mapping and visualising the entire SCs (Tier 1, 2, & 3) helps to identify critical nodes with risks and respond accordingly. Tools like I4.0, Digital Twins, and Value Stream Mapping can facilitate better visualisation.
Integration	Aligning firm ESG commitment and Technology	Firm's ESG commitment requires real-time monitoring of emissions, traceability of ethically and socially responsible networks, and compliance with global standards to facilitate better decision-making and minimise disruptions. The integration is possible through I4.0 (Cloud computing, IoT, AI, Blockchain, Big Data Analytics) to improve visibility and traceability of SCs in reducing environmental and compliance risk and enhancing data-driven decision-making.
Sustainability	Building sustainable practices	Implementing ESG commitment, SSCD and CE practices in the design of SCs to embed sustainability into SCs and minimise climate-related risks to achieve environmental efficiency.
Capabilities	Firm's capabilities	Develop sustainable, operational, technological, and human capabilities to build cross-functional teams that address complex disruption challenges and achieve resilience and environmental performance.

Source: Authors' own work

Our study also provides implications for policymakers. First, the research suggests that policymakers should establish ESG guidelines, enabling firms to integrate them into their business processes to meet the UN SDGs. Secondly, governments should introduce digital infrastructure investments for emerging markets to improve the digital connectivity and subsidise or incentivise e-commerce or ESG-related platforms to integrate sustainable practices. Thirdly, fostering dynamic capabilities through policy to develop innovative ecosystems as green tech hubs will nurture the capabilities to address ESG, sustainability, and SCRES challenges. Fourthly, the development of frameworks for firms' entrepreneurial orientation, ESG alignment and innovation decision support models to develop dynamic capabilities. Fifthly, policymakers can provide financial incentives, such as tax breaks, to firms that adopt technology and sustainable practices to minimise waste and focus on broader environmental and climate impacts. Lastly, policymakers can invest in capacity- and knowledge-building teaching programs by using case studies, simulations, or experiential learning to

enhance workforce skills across firms. This can foster capacity building, knowledge sharing of sustainable practices and improving innovation in business models to promote sustainability and achieve resilience in turbulent times.

6. Conclusion, limitations and future research

This study investigates the antecedents and outcomes of firms' SCRES, focusing on technology and sustainability capabilities. I4.0 and ESG commitment are considered two key resources of CE and SSCD, as they are the main capabilities required to reshape SC and achieve resilience. EP is also examined as an outcome of SCRES. The research model is tested by PLS-SEM based on 261 responses from the Top 1,000 industrial enterprises in Türkiye. All hypotheses are accepted except H4, which hypothesised a direct positive impact of ESG commitment on CE practices. The results of all hypotheses are presented and justified in the discussion section, along with theoretical and managerial contributions. Results show that CE practices and SSCD are supported by I4.0 and ESG commitments, while CE practices and SSCD enable SCRES. Results also show that achieving resilience can have a positive impact on the economic performance of firms.

Some limitations exist in our study. We only measured the impact of SCRES on the economic dimension of sustainability. Limitations with only EP were necessary, considering the complex model in our research. Future studies can also measure the impact of SCRES on social performance. Also, advanced capabilities like CE and SSCD often require learning and training among different intra- and inter-organisational teams. This necessity can lead organisations to invest more in the human side of their SCs, which can positively impact social performance. Thus, future research can further investigate the interlink between environmental and social dimensions in SCs. The full mediation of SSCD between ESG commitment and CE practices also calls for future research, as the non-significant direct relation between ESG commitment and CE should be further examined. Future research might explore how Industry 4.0 technologies affect the strength or nature of connections between circular economy practices, sustainable supply chain design, and overall supply chain performance. One limitation of this study is the reliance on a single respondent per firm, which may introduce bias due to individual perceptions or limited visibility across the entire organisation. While this issue is addressed by surveying managers with relevant roles and responsibilities, future research could benefit from a multi-respondent design and cross-validation.

While this study conceptualised I4.0 as a technological resource base supporting the development of dynamic capabilities, we did not differentiate between specific technologies such as IoT, AI, Big Data or cloud computing in their contributions to supply chain resilience. Future research could investigate which particular I4.0 technologies are most critical for enhancing resilience outcomes. Such an approach would provide a more granular understanding of which digital tools strengthen resilience and performance in different industries.

Another limitation is that the generalisability of this study's findings is limited by its focus on large firms operating in Türkiye. While this context provides meaningful insights into an emerging economy where digital transformation and sustainability initiatives are rapidly evolving, the results may not fully represent smaller firms or those in different countries.

References

Agarwal, V., Hameed, A. Z., Malhotra, S., Mathiyazhagan, K., Alathur, S., & Appolloni, A. (2023). Role of Industry 4.0 in agile manufacturing to achieve sustainable development. *Business Strategy and the Environment*, *32*(6), 3671–3688. https://doi.org/10.1002/bse.3321

Ageron, B., Gunasekaran, A., & Spalanzani, A. (2012). Sustainable supply management: An empirical study. *International Journal of Production Economics*, *140*(1), 168–182. https://doi.org/10.1016/j.ijpe.2011.04.007

Akbari, M., & Hopkins, J. L. (2022). Digital technologies as enablers of supply chain sustainability in an emerging economy. *Operations Management Research*, *15*(3–4), 689–710. https://doi.org/10.1007/s12063-021-00226-8

Alkaraan, F., Albitar, K., Hussainey, K., & Venkatesh, V. (2022). Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG). *Technological Forecasting and Social Change*, *175*, 121423. https://doi.org/10.1016/j.techfore.2021.121423

Aman, S., & Seuring, S. (2023). Analysing developing countries approaches of supply chain resilience to COVID-19. *The International Journal of Logistics Management*, *34*(4), 909–934. https://doi.org/10.1108/IJLM-07-2021-0362

Ambrosini, V., & Bowman, C. (2009). What are dynamic capabilities and are they a useful construct in strategic management? *International Journal of Management Reviews*, *11*(1), 29–49. https://doi.org/10.1111/j.1468-2370.2008.00251.x

Arimany Serrat, N., Arribas-Ibar, M., & Erdoğan, G. (2025). Fast Fashion Sector: Business Models, Supply Chains, and European Sustainability Standards. *Systems*, *13*(6), 405. https://doi.org/10.3390/systems13060405

Attah-Boakye, R., Adams, K., Hernandez-Perdomo, E., Yu, H., & Johansson, J. (2023). Resource re-orchestration and firm survival in crisis periods: The role of business models of technology MNEs during COVID-19. *Technovation*, *125*, 102769. https://doi.org/10.1016/j.technovation.2023.102769

Bag, S., Srivastava, G., Cherrafi, A., Ali, A., & Singh, R. K. (2024). Data-driven insights for circular and sustainable food supply chains: An empirical exploration of big data and predictive analytics in enhancing social sustainability performance. *Business Strategy and the Environment*, *33*(2), 1369–1396. https://doi.org/10.1002/bse.3554

Bagozzi, R. P., & Yi, Y. (2012). Specification, evaluation, and interpretation of structural equation models. *Journal of the Academy of Marketing Science*, *40*(1), 8–34. https://doi.org/10.1007/s11747-011-0278-x

Balci, G., & Ali, S. I. (2024). The relationship between information processing capabilities, Net-Zero capability and supply chain performance. *Supply Chain Management: An International Journal*, *29*(2), 351–370. https://doi.org/10.1108/SCM-06-2023-0320

Bao, X., Sun, B., Han, M., Mai, Q., & Lin, H. (2023). Corporate integrity culture on environmental, social, and governance (ESG) performance. *Corporate Social Responsibility and Environmental Management*, csr.2637. https://doi.org/10.1002/csr.2637

Batista, L., Gong, Y., Pereira, S., Jia, F., & Bittar, A. (2019). Circular supply chains in emerging economies – a comparative study of packaging recovery

ecosystems in China and Brazil. *International Journal of Production Research*, *57*(23), 7248–7268. https://doi.org/10.1080/00207543.2018.1558295

Belhadi, A., Kamble, S., Gunasekaran, A., & Mani, V. (2022). Analyzing the mediating role of organizational ambidexterity and digital business transformation on industry 4.0 capabilities and sustainable supply chain performance. *Supply Chain Management: An International Journal*, *27*(6), 696–711. https://doi.org/10.1108/SCM-04-2021-0152

Belhadi, A., Venkatesh, M., Kamble, S., & Abedin, M. Z. (2024). Data-driven digital transformation for supply chain carbon neutrality: Insights from cross-sector supply chain. *International Journal of Production Economics*, *270*, 109178. https://doi.org/10.1016/j.ijpe.2024.109178

Bellamy, M. A., Dhanorkar, S., & Subramanian, R. (2020). Administrative environmental innovations, supply network structure, and environmental disclosure. *Journal of Operations Management*, *66*(7–8), 895–932. https://doi.org/10.1002/joom.1114

Benabdellah, G. C., Zekhnini, K., Benabdellah, A. C., Lu, Q., Wu, J., & Khan, Z. (2024). Building dynamic capabilities in supplier selection in industry 4.0 era: A literature review. *Journal of General Management*, *50*(1), 53–64. https://doi.org/10.1177/03063070241263647

Bensaou, M., & Venkatraman, N. (1995). Configurations of Interorganizational Relationships: A Comparison Between U.S. and Japanese Automakers. *Management Science*, *41*(9), 1471–1492. https://doi.org/10.1287/mnsc.41.9.1471

Beske, P., Land, A., & Seuring, S. (2014). Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of

the literature. *International Journal of Production Economics*, *152*, 131–143. https://doi.org/10.1016/j.ijpe.2013.12.026

Bhatnagar, B., & Dixit, V. (2025). Resilient supply chains: Advancing technology integration with pre- and post-disruption technology roadmap. *Journal of Enterprise Information Management*. https://doi.org/10.1108/jeim-07-2023-0411

Birkel, H., & Müller, J. M. (2025). Resilient by nature or technology? How Industry 4.0 enhances Supply Chain Resilience until 2035. *Supply Chain Management: An International Journal*, *30*(3), 304–322. https://doi.org/10.1108/scm-07-2023-0340

Blackhurst, J., Dunn, K. S., & Craighead, C. W. (2011). An Empirically Derived Framework of Global Supply Resiliency: Framework of Global Supply Resiliency. *Journal of Business Logistics*, *32*(4), 374–391. https://doi.org/10.1111/j.0000-0000.2011.01032.x

Carraresi, L., & Bröring, S. (2021). How does business model redesign foster resilience in emerging circular value chains? *Journal of Cleaner Production*, *289*, 125823. https://doi.org/10.1016/j.jclepro.2021.125823

Centobelli, P., Cerchione, R., Esposito, E., Passaro, R., & Shashi. (2021). Determinants of the transition towards circular economy in SMEs: A sustainable supply chain management perspective. *International Journal of Production Economics*, *242*, 108297. https://doi.org/10.1016/j.ijpe.2021.108297

Chan, E. M.-H., Cheung, J., Leslie, C. A., Lau, Y.-Y., Suen, D. W.-S., & Tsang, C.-W. (2024). Revolutionizing the Textile and Clothing Industry: Pioneering

Sustainability and Resilience in a Post-COVID Era. *Sustainability*, *16*(6), 2474. https://doi.org/10.3390/su16062474

Chaouni Benabdellah, A., Zekhnini, K., Cherrafi, A., Garza-Reyes, J. A., Kumar, A., & El Baz, J. (2023). Blockchain technology for viable circular digital supplychains: An integrated approach for evaluating the implementation barriers. *Benchmarking: An International Journal*, *30*(10), 4397–4424. https://doi.org/10.1108/bij-04-2022-0240

Chari, A., Niedenzu, D., Despeisse, M., Machado, C. G., Azevedo, J. D., Boavida-Dias, R., & Johansson, B. (2022). Dynamic capabilities for circular manufacturing supply chains—Exploring the role of Industry 4.0 and resilience. *Business Strategy and the Environment*, *31*(5), 2500–2517. https://doi.org/10.1002/bse.3040

Chatterjee, S., Chaudhuri, R., Gupta, S., Mangla, S. K., & Kamble, S. (2023). Examining the influence of industry 4.0 in healthcare supply chain performance: Moderating role of environmental dynamism. *Journal of Cleaner Production*, *427*, 139195. https://doi.org/10.1016/j.jclepro.2023.139195

Daft, R. L., & Weick, K. E. (1984). Toward a Model of Organizations as Interpretation Systems. *The Academy of Management Review*, *9*(2), 284. https://doi.org/10.2307/258441

Dennehy, D., Oredo, J., Spanaki, K., Despoudi, S., & Fitzgibbon, M. (2021). Supply chain resilience in mindful humanitarian aid organizations: The role of big data analytics. *International Journal of Operations & Production Management*, *41*(9), 1417–1441. https://doi.org/10.1108/IJOPM-12-2020-0871

Di Maria, E., De Marchi, V., & Galeazzo, A. (2022). Industry 4.0 technologies and circular economy: The mediating role of supply chain integration. *Business*

Strategy and the Environment, *31*(2), 619–632. https://doi.org/10.1002/bse.2940

Díaz-Chao, Á., Ficapal-Cusí, P., & Torrent-Sellens, J. (2021). Environmental assets, industry 4.0 technologies and firm performance in Spain: A dynamic capabilities path to reward sustainability. *Journal of Cleaner Production*, *281*, 125264. https://doi.org/10.1016/j.jclepro.2020.125264

Eggert, J., & Hartmann, J. (2023). Sustainable supply chain management – a key to resilience in the global pandemic. *Supply Chain Management: An International Journal*, *28*(3), 486–507. https://doi.org/10.1108/SCM-10-2021-0463

El Baz, J., & Ruel, S. (2021). Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. *International Journal of Production Economics*, *233*, 107972. https://doi.org/10.1016/j.ijpe.2020.107972

El Baz, J., & Ruel, S. (2024). Achieving social performance through digitalization and supply chain resilience in the COVID-19 disruption era: An empirical examination based on a stakeholder dynamic capabilities view. *Technological Forecasting and Social Change*, *201*, 123209. https://doi.org/10.1016/j.techfore.2024.123209

Ellen Macarthur Foundation. (2015). *Growth within: A circular economy vision for a competitive Europe, 2015*. https://www.mckinsey.com/capabilities/sustainability/our-insights/growth-within-a-circular-economy-vision-for-a-competitive-europe

Fahimnia, B., & Jabbarzadeh, A. (2016). Marrying supply chain sustainability and resilience: A match made in heaven. *Transportation Research Part E: Logistics and Transportation Review*, *91*, 306–324. https://doi.org/10.1016/j.tre.2016.02.007

Fan, H., Cheng, T. C. E., Li, G., & Lee, P. K. C. (2016). The Effectiveness of Supply Chain Risk Information Processing Capability: An Information Processing Perspective. *IEEE Transactions on Engineering Management*, *63*(4), 414–425. https://doi.org/10.1109/TEM.2016.2598814

Fatimah, Y. A., Kannan, D., Govindan, K., & Hasibuan, Z. A. (2023). Circular economy e-business model portfolio development for e-business applications: Impacts on ESG and sustainability performance. *Journal of Cleaner Production*, *415*, 137528. https://doi.org/10.1016/j.jclepro.2023.137528

Ferreira, J., Coelho, A., & Moutinho, L. (2020). Dynamic capabilities, creativity and innovation capability and their impact on competitive advantage and firm performance: The moderating role of entrepreneurial orientation. *Technovation*, *92–93*, 102061. https://doi.org/10.1016/j.technovation.2018.11.004

Fisher, O. J., Watson, N. J., Escrig, J. E., & Gomes, R. L. (2020). Intelligent Resource Use to Deliver Waste Valorisation and Process Resilience in Manufacturing Environments: Moving towards sustainable process manufacturing. *Johnson Matthey Technology Review*, *64*(1), 93–99. https://doi.org/10.1595/205651320X15735483214878

Fornell, C., & Larcker, D. F. (1981). Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. *Journal of Marketing Research*, *18*(1), 39–50. https://doi.org/10.1177/002224378101800104

Frederico, G. F., Kumar, V., Garza-Reyes, J. A., Kumar, A., & Agrawal, R. (2023). Impact of I4.0 technologies and their interoperability on performance: Future pathways for supply chain resilience post-COVID-19. *The International Journal of Logistics Management*, *34*(4), 1020–1049. https://doi.org/10.1108/ijlm-03-2021-0181

Galbraith, J. R. (1974). Organization Design: An Information Processing View. *Interfaces*, *4*(3), 28–36. https://doi.org/10.1287/inte.4.3.28

Gebhardt, M., Spieske, A., & Birkel, H. (2022). The future of the circular economy and its effect on supply chain dependencies: Empirical evidence from a Delphi study. *Transportation Research Part E: Logistics and Transportation Review*, *157*, 102570. https://doi.org/10.1016/j.tre.2021.102570

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, *252*, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Ghobakhloo, M., Iranmanesh, M., Foroughi, B., Tseng, M.-L., Nikbin, D., & Khanfar, A. A. A. (2025). Industry 4.0 digital transformation and opportunities for supply chain resilience: A comprehensive review and a strategic roadmap. *Production Planning & Control*, *36*(1), 61–91. https://doi.org/10.1080/09537287.2023.2252376

Gualandris, J., Longoni, A., Luzzini, D., & Pagell, M. (2021). The association between supply chain structure and transparency: A large-scale empirical study. *Journal of Operations Management*, *67*(7), 803–827. https://doi.org/10.1002/joom.1150

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, *31*(1), 2–24. https://doi.org/10.1108/EBR-11-2018-0203

Hair, J. F., Sarstedt, M., Ringle, C. M., & Gudergan, S. P. (2018). *Advanced Issues in Partial Least Squares Structural Equation Modeling (PLS-SEM)*. SAGE.

Harman. (1967). *A single factor test of common method variance*. *35*, 359–378.

Hmamed, H., Cherrafi, A., Benghabrit, A., Tiwari, S., & Sharma, P. (2024). The adoption of I4.0 technologies for a sustainable and circular supply chain: An industry-based SEM analysis from the textile sector. *Business Strategy and the Environment*, *33*(4), 2949–2968. https://doi.org/10.1002/bse.3645

Hohenstein, N. O., Feisel, E., Hartmann, E., & Giunipero, L. (2015). *Research on the phenomenon of supply chain resilience—A systematic review and paths for further investigation*. *45*(1), 90–117.

Iqbal, M. W., & Kang, Y. (2024). Circular economy of food: A secondary supply chain model on food waste management incorporating IoT based technology. *Journal of Cleaner Production*, *435*, 140566. https://doi.org/10.1016/j.jclepro.2024.140566

Istanbul Chamber of Industry. (2024). *Istanbul Chamber of Industry*. https://www.iso.org.tr/

Ivanov, D. (2018). Revealing interfaces of supply chain resilience and sustainability: A simulation study. *International Journal of Production Research*, *56*(10), 3507–3523. https://doi.org/10.1080/00207543.2017.1343507

Ivanov, D. (2021). *Introduction to supply chain resilience: Management, modelling, technology*. Springer Nature.

Ivanov, D. (2024). Supply chain resilience: Conceptual and formal models drawing from immune system analogy. *Omega*, *127*, 103081. https://doi.org/10.1016/j.omega.2024.103081

Ivanov, D., Dolgui, A., & Sokolov, B. (2022). Cloud supply chain: Integrating Industry 4.0 and digital platforms in the “Supply Chain-as-a-Service”. *Transportation Research Part E: Logistics and Transportation Review*, *160*, 102676. https://doi.org/10.1016/j.tre.2022.102676

Jabbar, A., Akhtar, P., & Ali, S. I. (2024). The interplay between blockchain and big data analytics for enhancing supply chain value creation in micro, small, and medium enterprises. *Annals of Operations Research*. https://doi.org/10.1007/s10479-024-06415-5

Jabbarzadeh, A., Fahimnia, B., & Sabouhi, F. (2018). Resilient and sustainable supply chain design: Sustainability analysis under disruption risks. *International Journal of Production Research*, *56*(17), 5945–5968. https://doi.org/10.1080/00207543.2018.1461950

Jabbarzadeh, A., Haughton, M., & Pourmehdi, F. (2019). A robust optimization model for efficient and green supply chain planning with postponement strategy. *International Journal of Production Economics*, *214*, 266–283. https://doi.org/10.1016/j.ijpe.2018.06.013

Jain, N. K., Chakraborty, K., & Choudhary, P. (2024). Building supply chain resilience through industry 4.0 base technologies: Role of supply chain visibility and environmental dynamism. *Journal of Business & Industrial Marketing*, *39*(8), 1750–1763. https://doi.org/10.1108/jbim-09-2023-0550

Jeong, H., Song, C., Kim, S., & Shin, K. (2023). Quantum jump in biopharmaceutical industry: A case of Korea’s catching up with Europe and US. *European*

Planning Studies, *31*(5), 885–904. https://doi.org/10.1080/09654313.2022.2132781

Junaid, M., Du, J., Mubarik, M. S., & Shahzad, F. (2024). Creating a sustainable future through INDUSTRY 4.0 technologies: Untying the role of circular economy practices and supply chain visibility. *Business Strategy and the Environment*, bse.3777. https://doi.org/10.1002/bse.3777

Junaid, M., Zhang, Q., Cao, M., & Luqman, A. (2023). Nexus between technology enabled supply chain dynamic capabilities, integration, resilience, and sustainable performance: An empirical examination of healthcare organizations. *Technological Forecasting and Social Change*, *196*, 122828. https://doi.org/10.1016/j.techfore.2023.122828

Kähkönen, A.-K., Evangelista, P., Hallikas, J., Immonen, M., & Lintukangas, K. (2023). COVID-19 as a trigger for dynamic capability development and supply chain resilience improvement. *International Journal of Production Research*, *61*(8), 2696–2715. https://doi.org/10.1080/00207543.2021.2009588

Kamble, S., Gunasekaran, A., & Dhone, N. C. (2020). Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies. *International Journal of Production Research*, *58*(5), 1319–1337. https://doi.org/10.1080/00207543.2019.1630772

Karmaker, C. L., Aziz, R. A., Ahmed, T., Misbauddin, S. M., & Moktadir, Md. A. (2023). Impact of industry 4.0 technologies on sustainable supply chain performance: The mediating role of green supply chain management practices and circular economy. *Journal of Cleaner Production*, *419*, 138249. https://doi.org/10.1016/j.jclepro.2023.138249

Kennedy, S., & Linnenluecke, M. K. (2022a). Circular economy and resilience: A research agenda. *Business Strategy and the Environment*, *31*(6), 2754–2765. https://doi.org/10.1002/bse.3004

Kennedy, S., & Linnenluecke, M. K. (2022b). Circular economy and resilience: A research agenda. *Business Strategy and the Environment*, *31*(6), 2754–2765. https://doi.org/10.1002/bse.3004

Khan, O., Daddi, T., & Iraldo, F. (2020). The role of dynamic capabilities in circular economy implementation and performance of companies. *Corporate Social Responsibility and Environmental Management*, *27*(6), 3018–3033. https://doi.org/10.1002/csr.2020

Khan, S. A. R., Tabish, M., & Zhang, Y. (2023). Embracement of industry 4.0 and sustainable supply chain practices under the shadow of practice-based view theory: Ensuring environmental sustainability in corporate sector. *Journal of Cleaner Production*, *398*, 136609. https://doi.org/10.1016/j.jclepro.2023.136609

Knoernschild, E. (2022). *Nike Flyknit's Environmental Impact*. https://www.linkedin.com/pulse/nike-flyknits-environmental-impact-ella-knoernschild/

Kock, F., Berbekova, A., & Assaf, A. G. (2021). Understanding and managing the threat of common method bias: Detection, prevention and control. *Tourism Management*, *86*, 104330. https://doi.org/10.1016/j.tourman.2021.104330

Köhler, J., Sönnichsen, S. D., & Beske-Jansen, P. (2022). Towards a collaboration framework for circular economy: The role of dynamic capabilities and open innovation. *Business Strategy and the Environment*, *31*(6), 2700–2713. https://doi.org/10.1002/bse.3000

Kudrenko, I., Mukhametov, A., & Aslanov, E. S. (2025). Structural modification of supply chains in the imperatives of circular economy. *Journal of Innovation and Entrepreneurship*, *14*(1). https://doi.org/10.1186/s13731-025-00515-7

Kumar, M., Raut, R. D., Mangla, S. K., Chowdhury, S., & Choubey, V. K. (2024). Moderating ESG compliance between industry 4.0 and green practices with green servitization: Examining its impact on green supply chain performance. *Technovation*, *129*, 102898. https://doi.org/10.1016/j.technovation.2023.102898

Kumar, P., Sharma, D., & Pandey, P. (2023). Coordination mechanisms for digital and sustainable textile supply chain. *International Journal of Productivity and Performance Management*, *72*(6), 1533–1559. https://doi.org/10.1108/IJPPM-11-2020-0615

Laskurain-Iturbe, I., Arana-Landín, G., Landeta-Manzano, B., & Uriarte-Gallastegi, N. (2021). Exploring the influence of industry 4.0 technologies on the circular economy. *Journal of Cleaner Production*, *321*, 128944. https://doi.org/10.1016/j.jclepro.2021.128944

Le, M.-H., & Phi Tran, P. (2025). Managing supply chain resilience in climate and disaster-prone environments: A bibliometric analysis. *Competitiveness Review: An International Business Journal*. https://doi.org/10.1108/cr-01-2025-0003

Lei, Z., Cai, S., Cui, L., Wu, L., & Liu, Y. (2023). How do different Industry 4.0 technologies support certain Circular Economy practices? *Industrial Management & Data Systems*, *123*(4), 1220–1251. https://doi.org/10.1108/IMDS-05-2022-0270

Li, G., Xue, J., Li, N., & Ivanov, D. (2022). Blockchain-supported business model design, supply chain resilience, and firm performance. *Transportation Research Part E: Logistics and Transportation Review*, *163*, 102773. https://doi.org/10.1016/j.tre.2022.102773

Li, Y., Dai, J., & Cui, L. (2020). The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. *International Journal of Production Economics*, *229*, 107777. https://doi.org/10.1016/j.ijpe.2020.107777

Lin, K.-Y., & Lin, Y.-K. (2024). Sustainable supply chain evaluation with supplier sustainability in terms of reliability. *Annals of Operations Research*. https://doi.org/10.1007/s10479-024-05970-1

Liu, J., Lau, S., Liu, S. S., & Hu, Y. (2024). How Firm's Commitment to ESG Drives Green and Low-Carbon Transition: A Longitudinal Case Study from Hang Lung Properties. *Sustainability*, *16*(2), 711. https://doi.org/10.3390/su16020711

Lopes De Sousa Jabbour, A. B., Chiappetta Jabbour, C. J., Choi, T.-M., & Latan, H. (2022). 'Better together': Evidence on the joint adoption of circular economy and industry 4.0 technologies. *International Journal of Production Economics*, *252*, 108581. https://doi.org/10.1016/j.ijpe.2022.108581

Lopes De Sousa Jabbour, A. B., Latan, H., Chiappetta Jabbour, C. J., & Seles, B. M. R. P. (2023). Does applying a circular business model lead to organizational resilience? Mediating effects of industry 4.0 and customers integration. *Technological Forecasting and Social Change*, *194*, 122672. https://doi.org/10.1016/j.techfore.2023.122672

López-Concepción, A., Gil-Lacruz, A. I., & Saz-Gil, I. (2022). Stakeholder engagement, Csr development and Sdgs compliance: A systematic review from 2015 to 2021. *Corporate Social Responsibility and Environmental Management*, *29*(1), 19–31. https://doi.org/10.1002/csr.2170

Lu, H., Zhao, G., & Liu, S. (2024). Integrating circular economy and Industry 4.0 for sustainable supply chain management: A dynamic capability view. *Production Planning & Control*, *35*(2), 170–186. https://doi.org/10.1080/09537287.2022.2063198

Lucía Sabogal-De La Pava, M., Julio Vidal-Holguín, C., Fernando Manotas-Duque, D., & José Bravo-Bastidas, J. (2021). Sustainable supply chain design considering indicators of value creation. *Computers & Industrial Engineering*, *157*, 107294. https://doi.org/10.1016/j.cie.2021.107294

Luo, C., Zhang, D., Linderman, K., & Ni, J. (2024). Shared goals and vision in supply chain: A mediation model of prevention-oriented practices and compliance-oriented practices. *European Journal of Innovation Management*. https://doi.org/10.1108/EJIM-11-2023-0995

Luthra, S., Garg, D., & Haleem, A. (2013). *Identifying and ranking of strategies to implement green supply chain management in Indian manufacturing industry using Analytical Hierarchy Process*. *6*(4), 930–962.

MacKenzie, S. B., & Podsakoff, P. M. (2012). Common Method Bias in Marketing: Causes, Mechanisms, and Procedural Remedies. *Journal of Retailing*, *88*(4), 542–555. https://doi.org/10.1016/j.jretai.2012.08.001

Mari, S., Lee, Y., & Memon, M. (2014). Sustainable and Resilient Supply Chain Network Design under Disruption Risks. *Sustainability*, *6*(10), 6666–6686. https://doi.org/10.3390/su6106666

Matakanye, R. M., Van Der Poll, H. M., & Muchara, B. (2021). Do Companies in Different Industries Respond Differently to Stakeholders' Pressures When Prioritising Environmental, Social and Governance Sustainability Performance? *Sustainability*, *13*(21), 12022. https://doi.org/10.3390/su132112022

Medina-Serrano, R., Gonzalez, R., Gasco, J., & Llopis, J. (2019). Collaborative and sustainable supply chain practices: A case study. *Journal of Enterprising Communities: People and Places in the Global Economy*, *14*(1), 3–21. https://doi.org/10.1108/JEC-09-2019-0085

Melville, N., & Ramirez, R. (2008). Information technology innovation diffusion: An information requirements paradigm. *Information Systems Journal*, *18*(3), 247–273. https://doi.org/10.1111/j.1365-2575.2007.00260.x

Mishra, R., Singh, R. K., & Garza-Reyes, J. A. (2023). Interplay between absorptive capacity, analytics competence and sustainable economic performance of MSMEs in supply chain: The mediating role of risk resilience. *Annals of Operations Research*. https://doi.org/10.1007/s10479-023-05733-4

Mooneeapen, O., Abhayawansa, S., & Mamode Khan, N. (2022). The influence of the country governance environment on corporate environmental, social and governance (ESG) performance. *Sustainability Accounting, Management and Policy Journal*, *13*(4), 953–985. https://doi.org/10.1108/SAMPJ-07-2021-0298

Moreno-Camacho, C. A., Montoya-Torres, J. R., & Jaegler, A. (2023). Sustainable supply chain network design: A study of the Colombian dairy sector. *Annals of Operations Research*, *324*(1–2), 573–599. https://doi.org/10.1007/s10479-021-04463-9

Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, *15*(17), 6276. https://doi.org/10.3390/en15176276

Muafi, M., Hidayat, A., & Jufri, A. (2025). The Role of Moderating Digital Leadership and Digital Entrepreneurship in Enhancing the Resilience and Independence of MSMEs Towards Business Sustainability. *Review of Integrative Business and Economics Research*, *14*(2), 812–827.

Nandi, S., Sarkis, J., Hervani, A. A., & Helms, M. M. (2021). Redesigning Supply Chains using Blockchain-Enabled Circular Economy and COVID-19 Experiences. *Sustainable Production and Consumption*, *27*, 10–22. https://doi.org/10.1016/j.spc.2020.10.019

Napoleone, A., Bruzzone, A., Andersen, A.-L., & Brunoe, T. D. (2022). Fostering the Reuse of Manufacturing Resources for Resilient and Sustainable Supply Chains. *Sustainability*, *14*(10), 5890. https://doi.org/10.3390/su14105890

Negri, M., Cagno, E., Colicchia, C., & Sarkis, J. (2021). Integrating sustainability and resilience in the supply chain: A systematic literature review and a research agenda. *Business Strategy and the Environment*, *30*(7), 2858–2886. https://doi.org/10.1002/bse.2776

Ng, A. W., Nathwani, J., Fu, J., & Zhou, H. (2021). Green financing for global energy sustainability: Prospecting transformational adaptation beyond Industry 4.0. *Sustainability: Science, Practice and Policy*, *17*(1), 377–390. https://doi.org/10.1080/15487733.2021.1999079

Nitzl, C. (2016). The use of partial least squares structural equation modelling (PLS-SEM) in management accounting research: Directions for future theory

development. *Journal of Accounting Literature*, *37*(1), 19–35. https://doi.org/10.1016/j.acclit.2016.09.003

Pan, C.-L., Liao, H.-T., & Zhang, Y. (2023). Knowledge mapping of resilience and human rights in supply chains: A roadmapping taxonomy for twin green and digital transition design. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/fenvs.2023.1152345

Pandey, A. K., Daultani, Y., Pratap, S., Ip, A. W. H., & Zhou, F. (2025). Analyzing Industry 4.0 Adoption Enablers for Supply Chain Flexibility: Impacts on Resilience and Sustainability. *Global Journal of Flexible Systems Management*, *26*(S1), 1–24. https://doi.org/10.1007/s40171-024-00396-x

Patil, A., Shardeo, V., Dwivedi, A., Moktadir, Md. A., & Bag, S. (2023). Examining the interactions among smart supply chains and carbon reduction strategies: To attain carbon neutrality. *Business Strategy and the Environment*, bse.3547. https://doi.org/10.1002/bse.3547

Pieroni, M. P. P., McAloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production*, *215*, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

Piprani, A. Z., Khan, S. A. R., & Yu, Z. (2024). Driving success through digital transformation: Influence of Industry 4.0 on lean, agile, resilient, green supply chain practices. *Journal of Manufacturing Technology Management*, *35*(6), 1175–1198. https://doi.org/10.1108/jmtm-05-2023-0179

Polimetla, J. S., Sindhwani, R., & Bag, S. (2025). A Systematic Literature Review on Digital Twins in Circular Supply Chain Management. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.70038

Pop, P. C., Pintea, C.-M., Pop Sitar, C., & Hajdu-Măcelaru, M. (2015). An efficient Reverse Distribution System for solving sustainable supply chain network design problem. *Journal of Applied Logic*, *13*(2), 105–113. https://doi.org/10.1016/j.jal.2014.11.004

Premkumar, G., Ramamurthy, K., & Saunders, C. S. (2005). Information Processing View of Organizations: An Exploratory Examination of Fit in the Context of Interorganizational Relationships. *Journal of Management Information Systems*, *22*(1), 257–294. https://doi.org/10.1080/07421222.2003.11045841

Přívara, A., Rahman, A., Ognjanović, I., Hasnaoui, A., & Hachard, V. (2025). From Survival to Growth: Digital Strategies for Micro and Small Enterprises. *Strategic Change*. https://doi.org/10.1002/jsc.2666

Puriwat, W., & Tripopsakul, S. (2023). Sustainability Matters: Unravelling the Power of ESG in Fostering Brand Love and Loyalty across Generations and Product Involvements. *Sustainability*, *15*(15), 11578. https://doi.org/10.3390/su151511578

Quayson, M., Bai, C., Mahmoudi, A., Hu, W., Chen, W., & Omoruyi, O. (2023). Designing a decision support tool for integrating ESG into the natural resource extraction industry for sustainable development using the ordinal priority approach. *Resources Policy*, *85*, 103988. https://doi.org/10.1016/j.resourpol.2023.103988

Rajesh, R. (2021). Optimal trade-offs in decision-making for sustainability and resilience in manufacturing supply chains. *Journal of Cleaner Production*, *313*, 127596. https://doi.org/10.1016/j.jclepro.2021.127596

Rajesh, R., & Rajendran, C. (2020). Relating Environmental, Social, and Governance scores and sustainability performances of firms: An empirical

analysis. *Business Strategy and the Environment*, *29*(3), 1247–1267. https://doi.org/10.1002/bse.2429

Ramirez-Peña, M., Sánchez Sotano, A. J., Pérez-Fernandez, V., Abad, F. J., & Batista, M. (2020). Achieving a sustainable shipbuilding supply chain under I4.0 perspective. *Journal of Cleaner Production*, *244*, 118789. https://doi.org/10.1016/j.jclepro.2019.118789

Rashid, A., Rasheed, R., Ngah, A. H., Pradeepa Jayaratne, M. D. R., Rahi, S., & Tunio, M. N. (2024). Role of information processing and digital supply chain in supply chain resilience through supply chain risk management. *Journal of Global Operations and Strategic Sourcing*, *17*(2), 429–447. https://doi.org/10.1108/JGOSS-12-2023-0106

Reinartz, W., Haenlein, M., & Henseler, J. (2009). An empirical comparison of the efficacy of covariance-based and variance-based SEM. *International Journal of Research in Marketing*, *26*(4), 332–344. https://doi.org/10.1016/j.ijresmar.2009.08.001

Reyes, J., Mula, J., & Diaz-Madroñero, M. (2024). Quantitative insights into the integrated push and pull production problem for lean supply chain planning 4.0. *International Journal of Production Research*, *62*(17), 6251–6275. https://doi.org/10.1080/00207543.2024.2312205

Riaz, A., Rehman, H. M., Sohail, A., & Rehman, M. (2024). Industry 4.0 supply chain nexus: Sequential mediating effects of traceability, visibility and resilience on performance. *Asia Pacific Journal of Marketing and Logistics*. https://doi.org/10.1108/apjml-02-2024-0202

Ritzén, S., & Sandström, G. Ö. (2017). Barriers to the Circular Economy – Integration of Perspectives and Domains. *Procedia CIRP*, *64*, 7–12. https://doi.org/10.1016/j.procir.2017.03.005

Rodrigues, S. P., Gomes, L. D. C., Peres, F. A. P., Correa, R. G. D. F., & Baierle, I. C. (2025). A Framework for Leveraging Digital Technologies in Reverse Logistics Actions: A Systematic Literature Review. *Logistics*, *9*(2), 54. https://doi.org/10.3390/logistics9020054

Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between Circular Economy and Industry 4.0: A systematic literature review. *International Journal of Production Research*, *58*(6), 1662–1687. https://doi.org/10.1080/00207543.2019.1680896

Sabouhi, F., Jabalameli, M. S., & Jabbarzadeh, A. (2021). An optimization approach for sustainable and resilient supply chain design with regional considerations. *Computers & Industrial Engineering*, *159*, 107510. https://doi.org/10.1016/j.cie.2021.107510

Safari, A., Balicevac Al Ismail, V., Parast, M., Gölgeci, I., & Pokharel, S. (2024). Supply chain risk and resilience in startups, SMEs, and large enterprises: A systematic review and directions for research. *The International Journal of Logistics Management*, *35*(2), 680–709. https://doi.org/10.1108/IJLM-10-2022-0422

Saha, K., Karami, A., & Linus, V. O. (2025). A review of circular economy disruption research: Insights into industry 4.0 enabled circular economy framework for sustainability during turbulent times. *Cleaner Logistics and Supply Chain*, *16*, 100227. https://doi.org/10.1016/j.clscn.2025.100227

Sahoo, S., & Upadhyay, A. (2024). Improving triple bottom line (TBL) performance: Analyzing impacts of industry 4.0, lean six sigma and circular supply chain management. *Annals of Operations Research*. https://doi.org/10.1007/s10479-024-05945-2

Sánchez-García, E., Martínez-Falcó, J., Marco-Lajara, B., & Manresa-Marhuenda, E. (2024). Revolutionizing the circular economy through new technologies: A new era of sustainable progress. *Environmental Technology & Innovation*, *33*, 103509. https://doi.org/10.1016/j.eti.2023.103509

Sarkis, J. (2021). *Supply chain sustainability: Learning from the COVID-19 pandemic*. *41*(1), 63–73.

Sartzetaki, M., Karagkouni, A., & Dimitriou, D. (2025). Enterprise Strategic Management Upon Sustainable Value Creation: A Fuzzy Topis Evaluation Tool for Transport and Supply Chain Enterprises. *Sustainability*, *17*(11), 5011. https://doi.org/10.3390/su17115011

Satpathy, A. S., Sahoo, S. K., Mohanty, A., & Mohanty, P. P. (2025). Strategies for enhancements of MSME resilience and sustainability in the post-COVID-19 era. *Social Sciences & Humanities Open*, *11*, 101223. https://doi.org/10.1016/j.ssaho.2024.101223

Scarpellini, S., Marín-Vinuesa, L. M., Aranda-Usón, A., & Portillo-Tarragona, P. (2020). Dynamic capabilities and environmental accounting for the circular economy in businesses. *Sustainability Accounting, Management and Policy Journal*, *11*(7), 1129–1158. https://doi.org/10.1108/SAMPJ-04-2019-0150

Setyaningrum, R. P., Muafi, M., Indrajaya, S., & Rulianti, E. (2025). Contribution of Green Creativity to Business Sustainability: The Mediating Role of Green

Supply Chain Management and MSMEs Independence. *Review of Integrative Business and Economics Research*, *14*(2), 183–197.

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*(15), 1699–1710. https://doi.org/10.1016/j.jclepro.2008.04.020

Shareef, M. A., Dwivedi, Y. K., Kumar, V., Mahmud, R., Hughes, D. L., Rana, N. P., & Kizgin, H. (2020). The inherent tensions within sustainable supply chains: A case study from Bangladesh. *Production Planning & Control*, *31*(11–12), 932–949. https://doi.org/10.1080/09537287.2019.1695917

Sharma, A. K., & Sharma, S. K. (2023). Understanding the Impact of Covid-19 on MSMEs in India: Lessons for Resilient and Sustained Growth of Small Firms. *Journal of Small Business Strategy*, *33*(1), 70–83. https://doi.org/https://doi.org/10.53703/001c.72698

Sharma, M., Luthra, S., Joshi, S., Kumar, A., & Jain, A. (2023). Green logistics driven circular practices adoption in industry 4.0 Era: A moderating effect of institution pressure and supply chain flexibility. *Journal of Cleaner Production*, *383*, 135284. https://doi.org/10.1016/j.jclepro.2022.135284

Sindhwani, R., Hasteer, N., Behl, A., Varshney, A., & Sharma, A. (2023). Exploring “what,” “why” and “how” of resilience in MSME sector: A m-TISM approach. *Benchmarking: An International Journal*, *30*(6), 1884–1911. https://doi.org/10.1108/bij-11-2021-0682

Singh, J., Hamid, A. B. A., & Garza-Reyes, J. A. (2023). Supply chain resilience strategies and their impact on sustainability: An investigation from the automobile sector. *Supply Chain Management: An International Journal*, *28*(4), 787–802. https://doi.org/10.1108/SCM-06-2022-0225

Song, S., Lian, J., Skowronski, K., & Yan, T. (2024). Customer base environmental disclosure and supplier greenhouse gas emissions: A signaling theory perspective. *Journal of Operations Management*, *70*(3), 355–380. https://doi.org/10.1002/joom.1272

Sturm, S., Hohenstein, N.-O., & Hartmann, E. (2023). Linking entrepreneurial orientation and supply chain resilience to strengthen business performance: An empirical analysis. *International Journal of Operations & Production Management*, *43*(9), 1357–1386. https://doi.org/10.1108/IJOPM-07-2022-0418

Sudarsan, R., Sriram, R. D., Narayanan, A., Sarkar, P., Jae Hyun Lee, Lyons, K. W., & Kemmerer, S. J. (2010). Sustainable Manufacturing: Metrics, Standards, and Infrastructure - Workshop summary. *2010 IEEE International Conference on Automation Science and Engineering*, 5584472. https://doi.org/10.1109/COASE.2010.5584472

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, *28*(13), 1319–1350. https://doi.org/10.1002/smj.640

Teece, D. J., & Pisano, G. (1997). *The dynamic capabilities of firms—An introduction*. *3*(3), 537–556.

Teece, D. J., Pisano, G., & A, S. (1994). *Dynamic Capabilities and Strategic Management, revised edition*. University of California at Berkeley-Harvard University.

Tesla. (2023). *Impact Report 2023*. https://www.tesla.com/impact

Tortorella, G. L., Fogliatto, F. S., Saurin, T. A., Tonetto, L. M., & McFarlane, D. (2022). Contributions of Healthcare 4.0 digital applications to the resilience of

healthcare organizations during the COVID-19 outbreak. *Technovation*, *111*, 102379. https://doi.org/10.1016/j.technovation.2021.102379

Training for Ecommerce Adoption: Macro Assessment of Determinants. (2018). In R. Yadav & T. Mahara, *Advances in Business Information Systems and Analytics* (pp. 198–208). IGI Global. https://doi.org/10.4018/978-1-5225-4038-0.ch010

Tran, N. N., Penna, L. K., Heath, I. M., Arshad, M. Y., Gelonch, M. E., Tejada, J. L. O., Sarafraz, M. M., Suberu, J., Fregene, M., Rolfe, B., & Hessel, V. (2025). Integration of environmental, social and governance (ESG) into the supply chain of ammonia: Case study of Africa. *Sustainable Futures*, *10*, 100893. https://doi.org/10.1016/j.sftr.2025.100893

Trautmann, G., Turkulainen, V., Hartmann, E., & Bals, L. (2009). Integration In The Global Sourcing Organization—An Information Processing Perspective. *Journal of Supply Chain Management*, *45*(2), 57–74. https://doi.org/10.1111/j.1745-493X.2009.03163.x

Tsolakis, N., Niedenzu, D., Simonetto, M., Dora, M., & Kumar, M. (2021). Supply network design to address United Nations Sustainable Development Goals: A case study of blockchain implementation in Thai fish industry. *Journal of Business Research*, *131*, 495–519. https://doi.org/10.1016/j.jbusres.2020.08.003

Tushman, M. L., & Nadler, D. A. (1978). Information Processing as an Integrating Concept in Organizational Design. *The Academy of Management Review*, *3*(3), 613. https://doi.org/10.2307/257550

Veile, J. W., Schmidt, M.-C., Müller, J. M., & Voigt, K.-I. (2024). The transformation of supply chain collaboration and design through Industry 4.0. *International*

Journal of Logistics Research and Applications, *27*(6), 986–1014. https://doi.org/10.1080/13675567.2022.2148638

Wang, J., Ma, M., Dong, T., & Zhang, Z. (2023). Do ESG ratings promote corporate green innovation? A quasi-natural experiment based on SynTao Green Finance's ESG ratings. *International Review of Financial Analysis*, *87*, 102623. https://doi.org/10.1016/j.irfa.2023.102623

Wang, Y., Liu, Y., & Bai, X. (2024). Designing a new robust resilience supply chain network under partial distribution information. *Computers & Industrial Engineering*, *190*, 110028. https://doi.org/10.1016/j.cie.2024.110028

Warner, K. S. R., & Wäger, M. (2019). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. *Long Range Planning*, *52*(3), 326–349. https://doi.org/10.1016/j.lrp.2018.12.001

Wieland, A., & Durach, C. F. (2021). Two perspectives on supply chain resilience. *Journal of Business Logistics*, *42*(3), 315–322. https://doi.org/10.1111/jbl.12271

Yadav, R., & Mahara, T. (2019). Factors Affecting E-Commerce Adoption by Handicraft SMEs of India. *Journal of Electronic Commerce in Organizations*, *17*(4), 44–57. https://doi.org/10.4018/jeco.2019100104

Yamamoto, T., Merciai, S., Mogollón, J. M., & Tukker, A. (2022). The role of recycling in alleviating supply chain risk–Insights from a stock-flow perspective using a hybrid input-output database. *Resources, Conservation and Recycling*, *185*, 106474. https://doi.org/10.1016/j.resconrec.2022.106474

Yan, F., Chen, L., Jia, F., & Liu, Y. (2023). Building supply chain resilience through collaborative innovation: An information processing theory perspective.

Journal of Digital Economy, *2*, 233–243. https://doi.org/10.1016/j.jdec.2024.01.004

Ye, Y., Lau, K. H., & Teo, L. (2023). Alignment of green supply chain strategies and operations from a product perspective. *The International Journal of Logistics Management*, *34*(6), 1566–1600. https://doi.org/10.1108/IJLM-11-2021-0557

Yoşumaz, İ., & Uzun, H. (2024). The relationship between industry 5.0 Process and ESG process: A qualitative analysis in the context of Türkiye's BIST Sustainability 25 Index white good sector. *Environmental Research and Technology*, *7*(4), 512–529. https://doi.org/10.35208/ert.1431800

Yu, W., Jacobs, M. A., Chavez, R., & Yang, J. (2019). Dynamism, disruption orientation, and resilience in the supply chain and the impacts on financial performance: A dynamic capabilities perspective. *International Journal of Production Economics*, *218*, 352–362. https://doi.org/10.1016/j.ijpe.2019.07.013

Zeng, H., Chen, X., Xiao, X., & Zhou, Z. (2017). Institutional pressures, sustainable supply chain management, and circular economy capability: Empirical evidence from Chinese eco-industrial park firms. *Journal of Cleaner Production*, *155*, 54–65. https://doi.org/10.1016/j.jclepro.2016.10.093

Zhang, A., Venkatesh, V. G., Wang, J. X., Mani, V., Wan, M., & Qu, T. (2023). Drivers of industry 4.0-enabled smart waste management in supply chain operations: A circular economy perspective in china. *Production Planning & Control*, *34*(10), 870–886. https://doi.org/10.1080/09537287.2021.1980909

Zheng, L., Chen, H., & Zheng, W. (2024). Exploring Environmental, Social, and Governance Factors Affecting Supply Chain Resilience: From Employees'

Perspectives. *Sustainability*, *16*(24), 11012. https://doi.org/10.3390/su162411012

Zioło, M., Bąk, I., & Spoz, A. (2023). Theoretical framework of sustainable value creation by companies. What do we know so far? *Corporate Social Responsibility and Environmental Management*, *30*(5), 2344–2361. https://doi.org/10.1002/csr.2489

Appendix. Survey measures

Measurement Items	Source(s)
Industry 4.0 *(1: Totally Disagree, 5: Totally Agree)*	
1. We use Industry 4.0 technologies such as the Internet of Things (IoT), Big Data, cloud computing and Artificial Intelligence (AI) to manage supply chain operations	(Belhadi et al., 2022; M. Sharma et al., 2023)
2. Industry 4.0 technologies help us to be better connected with our suppliers and partners	
3. Industry 4.0 technologies are partially or fully implemented in our company to have visibility of the operations	
4. Our company systematically extracts and analyses data from suppliers and partners using Industry 4.0 technologies	
ESG Commitment *(1: Very Low, 5: Very High)*	
1. Commitment to environmental protection and minimising the organisation's impact on the environment (such as Waste reduction, carbon emission reduction, developing greener products)	(Kumar et al., 2024; Puriwat & Tripopsakul, 2023)
2. Commitment to improve the organisation's impact on the wider society and workplace culture (such as community engagement, working conditions, equality among employees)	
3. Commitment to ethical and transparent governance of the organisation (such as accurate reporting to stakeholders, ensuring managers and partners are accountable of business decisions)	
Circular Economy Practices *(1: Totally Disagree, 5: Totally Agree)*	
1. A shift in the use of non-renewable raw materials towards renewable raw materials	(Lopes De Sousa Jabbour et al., 2023)

2. Reduction of waste and rework through new working methods and new technologies
3. Reuse, recycling, and remanufacturing initiatives
4. Development of dematerialised products and services
5. Replacement of current equipment and technologies with more disruptive ones

Sustainable supply chain design *(1: Totally Disagree, 5: Totally Agree)*

1. Clean energy, such as solar or wind, is used during production processes. (Centibel et al., 2021)
2. Environmentally friendly production technology and production processes are emphasised.
3. The firm attaches great importance to environmentally friendly product design (such as
4. green design, product life cycle analysis, etc.).
5. The firm optimises logistics facility location to reduce the demand for logistics
6. Efficient modes of transportation between logistics facilities are used
7. The development and implementation of rules and regulations in environmental protection
8. are evaluated when selecting dealers
9. The firm designs/optimises ways to recycle waste materials and spare parts.

Supply Chain Resilience *(1: Totally Disagree, 5: Totally Agree)*

1. Our organisation is well prepared to face the constraints of supply chain disruptions. (Dennehy et al., 2021; El Baz & Ruel, 2021)
2. Our organisation rapidly plans and executes contingency plans against supply chain disruptions.
3. Our organisation can adequately respond to supply chain disruptions by quickly restoring its operations.
4. Our organisation is flexible to accommodate disruptions in its supply chain.
5. Our organisation is able to cope with changes brought by supply chain disruptions.
6. Our organisation can return to its original state after being disrupted.
7. Our organisation can gain a superior state compared to its original state after being disrupted.

Economic performance *(Compare your company's performance with its in relation to the below items in recent years. 1: Much worse, 5: Much better)*

1) Profitability (Khan et al., 2023)
2) Market share
3) Sales growth

Source: Compiled by authors