Aleksi Harju

BUILDING SUPPLY CHAIN RESILIENCE IN THE AGE OF DIGITALIZATION

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LUT University

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Abstract

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In an era of rapid digital transformation and increasing sustainability pressures, global supply chains face unprecedented challenges in managing risks and building resilience. This dissertation explores how digitalization relates to organizations' ability to address these challenges by investigating its role in three key areas: procurement digitalization, technology service procurement, and mitigation of sustainability-related risks.

The findings demonstrate that procurement digitalization improves information processing capabilities, enabling more effective risk management and greater resilience in the face of supply chain disruptions. Technology service procurement introduces distinct risks, including over-dependence on service providers and failure to meet sustainability goals, which necessitate tailored strategies for managing operational risks and ensuring sustainability. Furthermore, the research uncovers mechanisms to address uncertainties in supply chain emissions reporting, highlighting the role of technology-driven information processing in mitigating sustainability risks and enhancing supply chain resilience.

The dissertation provides theoretical and practical insights into the evolving dynamics of modern supply chains. It emphasizes that while digitalization can increase supply chain resilience, it also introduces vulnerabilities that organizations must proactively manage. Addressing these risks requires a holistic approach that integrates information processing, collaborative supplier relationships, and sustainability-driven practices. Together, these findings offer insights for organizations on how to adapt to an era shaped by rapid technological advancement and escalating sustainability risks by adopting a more data-driven approach to managing risks and disruptions in supply chains.

Keywords: Supply chain resilience, risk management, digitalization, sustainability, procurement, supply chain emissions, technology outsourcing

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Aleksi Harju
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Contents

List of publications

This dissertation is based on the following papers. The rights have been granted by publishers to include the papers in the dissertation.

I. Harju, A., Hallikas, J., Immonen M., and Lintukangas, K. (2023). The impact of procurement digitalization on supply chain resilience: empirical evidence from Finland. *Supply Chain Management*, 28, (7), pp. 62-76.

II. Harju, A., Schaëfer, K., Hallikas, J., and Kähkönen, A-K. (2024). The role of risk management practices in IT service procurement: A case study from the financial services industry. *Journal of Purchasing and Supply Management,* 30, (2), pp. 1-17.

III. Harju, A., Karttunen E., and Hallikas, J. (2024) Understanding the systemic sources of uncertainty for the management of greenhouse gas emissions in supply chains. An earlier version of the paper was presented and included in the Proceedings of the 33rd IPSERA Conference, March 2024, PUC Rio, Rio de Janeiro, Brazil. Manuscript submitted for publication.

IV. Schaëfer, K., Harju, A., Kähkönen, A-K., and Hallikas, J. (2024). Sustainability meets service procurement: a case study in the ICT service sector. *International Journal of Production Research*, pp-1-20.

Author's contribution

Aleksi Harju is the principal author and investigator in publications I – III.

In Publication I, the author was substantially involved in conceptualization, data analysis, writing, revision and correspondence regarding the manuscript.

In Publication II, the author was substantially involved in conceptualization, data collection, data analysis, writing, revision and correspondence regarding the manuscript.

In Publication III, the author was substantially involved in conceptualization, data collection, data analysis, writing, revision and correspondence regarding the manuscript.

In Publication IV, the author was substantially involved in conceptualization, data collection, data analysis, writing, revision and correspondence regarding the manuscript.

Nomenclature

Environmental, social, and governance (ESG)
Sustainable supply management (SSM)
Supply chain (SC)
Supply chain risk management (SCRM)
Supply chain resilience (SCRES)
Organizational information processing theory (OIPT)
Practice-based view (PBV)
Supply chain practice view (SCPV)
Greenhouse gas emissions (GHG)

Declarations

Turnitin

The originality of this dissertation has been reviewed with the Turnitin similarity checking service.

Commercial software

This dissertation was prepared with the help of the following commercial software:

SmartPLS 4 - a statistical software designed for data management, advanced analytics, multivariate analysis, and business intelligence. SmartPLS 4 licensed software is provided by LUT University for the researchers. I used SmartPLS 4 in Publication I for the data analysis.

NVivo 12 - a qualitative data analysis software used for data coding, classification and analysis. NVivo licensed software is provided by LUT University for the researchers. I utilized NVivo 12 for the qualitative data coding and analysis in Publications I, II, and IV.

AI use

During the preparation of this doctoral dissertation, Aleksi Harju, the author of the dissertation, used ChatGPT in order to develop the presentation and grammar of textual information in the summary of the dissertation. After using ChatGPT, the author reviewed and edited the content and takes full responsibility for the content of the doctoral dissertation.

1 Introduction

1.1 Background

Recent unprecedented technological advancements and the growing imperative to address various sustainability challenges have put supply chains under intense pressure to adapt and evolve accordingly. Research shows that these pressures have led organizations to operate in increasingly risk-sensitive environments, where new uncertainties emerge and unanticipated disruptions threaten the continuity and performance of global supply chains (Fischer-Preßler *et al.*, 2020; Ghadge, Wurtmann, *et al.*, 2020; Van Hoek, 2020). This trend is evidenced by recent catastrophic events, such as the COVID-19 pandemic, which exposed vulnerabilities in supply chains worldwide by creating demand shocks, labour shortages, and transportation delays (Van Hoek, 2020; Belhadi *et al.*, 2021). The rapid adoption of digital tools and interconnectivity has made supply chains more efficient but also more vulnerable to IT system failures, cyberattacks, and data breaches (Ghadge, Weiß, *et al.*, 2020). Similarly, natural disasters such as earthquakes, hurricanes, and floods, increasingly disrupt supply chains, with climate change predicted to amplify both the frequency and intensity of such calamities, adding long-term instability to global operations (Sodhi and Tang, 2021; Intergovernmental Panel on Climate Change (IPCC), 2023).

In this specific context, the ability to improve supply chain resilience has become more critical than ever. However, as demonstrated by a succession of large-scale supply chain disruptions, maintaining supply chain resilience remains a formidable challenge. Traditional supply chain practices, which heavily emphasize optimization, efficiency, and cost reduction, often fall short of addressing the complexity and unpredictability of contemporary disruptions (Sodhi and Tang, 2021; Holgado *et al.*, 2024). For instance, the COVID-19 pandemic exposed these limitations when organizations across sectors struggled to adapt to simultaneous demand shocks, labour shortages, and logistical bottlenecks that impeded the flow of global goods and services (Van Hoek, 2020). These disruptions highlight the crucial need to enhance understanding of how to better maintain resilience in an increasingly interconnected and volatile supply chain environment.

For decades, it has been clear to organizational researchers that the management of risks and disruptions in organizations stems from deep-rooted uncertainty. In other words, the inability to avoid risks and effectively respond to supply chain disruptions is largely due to the high degrees of uncertainty in the operating environment. In this sense, uncertainty refers to the unpredictability and incomplete information that complicate planning and decision-making within the supply chain (van der Vorst and Beulens, 2002). In this context, scholars have long posited that an organization's capacity to design and maintain efficient operations under these conditions is directly linked to its information processing capabilities (Galbraith, 1974; Premkumar *et al.*, 2005; Fan *et al.*, 2017). As uncertainty increases, so does the need for information to clarify unknowns, and organizations must strive to balance information processing demands with their processing capacities.

Achieving an optimal fit between these factors is essential for stable operations, allowing organizations to identify potential disruptions early, assess their expected impacts, and coordinate timely responses (Tushman and Nadler, 1978).

Recent research consistently suggests that digitalization is a transformative force enabling supply chains to enhance their information processing capabilities and thus manage risks and prepare for disruptions more effectively (e.g., Yin *et al.*, 2024). This is due to the ability of digital technologies, such as real-time data analytics, cloud computing, and the Internet of Things, to provide unprecedented supply chain visibility and decision-making speed in supply chain management (Verhoef *et al.*, 2021; Kalaiarasan *et al.*, 2022). These technologies allow firms to access and process large volumes of data faster, facilitating predictive insights and more adaptive decision-making. For example, data-driven supply chain visibility enhances demand forecasting, supplier risk assessments, and inventory optimization (Kalaiarasan *et al.*, 2022), each integral to building resilience in the face of disruptions (Ali *et al.*, 2017; Ivanov *et al.*, 2019; El Baz and Ruel, 2021).

However, as supply chains grow more interconnected through digitalization, they also become more exposed to technology-driven risks (Colicchia *et al.*, 2019; Kessler *et al.*, 2022). For example, studies show that cyberattacks, system outages, and data breaches can disrupt operations across entire networks, often with significant financial and reputational repercussions (Ghadge, Weiß, *et al.*, 2020; Kessler *et al.*, 2022). These threats accentuate the need for organizations to develop practices that ensure stronger cybersecurity measures and enhance resilience of technological systems alongside traditional supply chain operations.

At the same time, sustainability-driven risks are rising in both frequency and severity, requiring data-driven approaches and sustainable practices that boost the resilience of supply chains and the broader planetary ecosystem (Wieland, 2021). For example, climate change-driven extreme weather events, ranging from wildfires to floods, are increasingly impacting supply chain operations by disrupting transportation routes, damaging infrastructure, and limiting the availability of raw materials (Sodhi and Tang, 2021; IPCC, 2023). Beyond the operational disruptions they cause, sustainability risks also expose organizations to regulatory, reputational, and financial pressures, as stakeholders increasingly demand transparency and action to minimize environmental impacts (Blanco, 2021). To navigate this shifting landscape, organizations must leverage digitalization and integrate data-driven supply chain risk management strategies to enhance sustainability. Beyond mitigating immediate risks, these approaches should extend beyond traditional frameworks to position resilience not only as a defensive measure but a proactive commitment to long-term sustainability (Holgado *et al.*, 2024).

Considering such complex and multifaceted issues, the purpose of this dissertation is to investigate how digitalization influences risk management and resilience in modern supply chains. As supply chains face mounting uncertainty from both operational disruptions and sustainability-related risks, digitalization presents new opportunities to upgrade risk management capabilities. At the same time, it introduces new vulnerabilities that organizations must proactively address. By exploring how digital technologies and data-driven practices strengthen risk management and resilience, this dissertation provides empirical insights into how organizations can better navigate uncertainty in modern supply chains.

1.2 Research gaps

Gap 1 – Digitalization in procurement and its role in improving supply chain resilience

The rapid digital transformation of global business has gained considerable attention in the supply chain and operations management literature, with many studies recognizing the broad potential of digital technologies, such as data analytics, artificial intelligence, and the Internet of Things, to streamline processes, improve visibility, and enhance decision-making across supply chains (e.g., Ivanov *et al.*, 2019; Verhoef *et al.*, 2021). However, while digitalization has been explored from a general supply chain perspective, research has largely overlooked its specific implications for procurement—a critical function that coordinates upstream flows and plays a major role in managing risks originating from the supply base (Zsidisin *et al.*, 2004).

Procurement digitalization is broadly defined as the use of digital technologies to support procurement-related activities (Srai and Lorentz, 2019). Although a couple of studies have examined procurement digitalization (Srai and Lorentz, 2019; Lorentz *et al.*, 2021), limited research has explored how procurement-specific digitalization contributes to resilience through information processing. Studies suggest that digital technologies can enable resilience through higher degrees of digital maturity and technology adoption (Viale and Zouari, 2020). These capabilities have the potential to improve risk management particularly in the procurement function by empowering organizations to anticipate, mitigate, and respond to supply-related uncertainties more effectively.

Understanding procurement digitalization's distinct impact is crucial, since procurement departments are often key stakeholders in supply chain risk management, dealing directly with suppliers and other upstream partners who may face their own disruptions. Without clear insights into how digitalization in procurement supports resilience, organizations may fail to fully leverage digital investments to fortify their supply chains against evolving risks. This gap is further emphasized by the increasing complexity of global supply networks and the rising expectation for procurement functions to manage not only costs but also risks, sustainability, and supplier reliability (Tummala and Schoenherr, 2011; Giannakis and Papadopoulos, 2016; Kähkönen *et al.*, 2023).

Gap 2 - Risk management in the context of ICT service procurement

Research on supply chain risk management has traditionally focused on product-based supply chains, where tangible goods, inventory flows, and production logistics are the central risk considerations (Ho *et al.*, 2015; Fan and Stevenson, 2018). While studies have contributed valuable insights into managing such risks, they have left a gap in understanding risk management in the context of service procurement (Wynstra *et al.*, 2015). From the perspective of digitalization, this gap is even more significant, since there is limited research on the management of risks and the continuity of purchased technology services. For example, the growing dependence on third-party IT providers of critical technology services has introduced unique vulnerabilities in both product- and service-based supply chains, such as service availability risks and cybersecurity threats. Similarly, a buyer organization's capability to manage sustainability as part of IT providers' performance is an important risk management consideration due to potential reputational risks and the need to manage service providers' public perception and brand (Selviaridis and Wynstra, 2015; Sengupta *et al.*, 2022).

Since IT service procurement and technology outsourcing significantly contribute to the digitalization of supply chains, understanding the management of risks and disruptions in this context is critical. IT service procurement differs fundamentally from product-based procurement due to the intangible and co-created nature of services, where quality depends not only on contractual specifications but also on sustained performance and adaptability (Ellram *et al.*, 2008; Lacity *et al.*, 2016). Moreover, IT services are often deeply embedded in an organization's operations. Disruptions of these services can cascade across multiple functions, negatively impacting overall supply chain performance (Ghadge, Weiß, *et al.*, 2020). The complexity of managing these services is further compounded by the relational dependencies that arise between a buyer organization and its service providers, since outsourced IT services require closer and continuous coordination, as well as collaborative risk management to ensure service performance (Luzzini *et al.*, 2014; Raddats *et al.*, 2017).

Despite these notions, current research has provided limited insights into how organizations can systematically integrate risk and disruption management practices into their service procurement (Ellram *et al.*, 2008; Wynstra *et al.*, 2015; Heinis *et al.*, 2022). As technology services become central to supply chains, there is an increasing for a broader understanding of risk management to better address the specific challenges of outsourced technology services and ensure the continuity of digital service operations that support supply chain management. Such considerations extend to investigating the sustainability of IT suppliers and outsourced service production, which has been sparsely researched (Hofmann *et al.*, 2020).

Gap 3 - Addressing sustainability-related uncertainties through organizational information processing

The intensifying impacts of climate change have highlighted the urgent need for supply chains to adopt more sustainable practices, as the risk of climate-driven disruptions continues to escalate (IPCC, 2023). A critical component of sustainability-oriented risk management involves an organization's ability to identify, measure, and manage environmental impacts across the entire supply chain (Blanco, 2021; Vieira *et al.*, 2024). For example, indirect carbon emissions, which encompass upstream and downstream activities, often represent the largest share of a company's total carbon footprint, yet they remain among the most complex and challenging to measure and manage effectively. This complexity introduces significant uncertainties in reporting and decision-making, potentially limiting an organization's ability to mitigate sustainability-related risks effectively (Dahlmann and Roehrich, 2019; Ghadge, Wurtmann, *et al.*, 2020).

Research suggests that information processing plays a crucial role in mitigating sustainability-related uncertainties (Busse *et al.*, 2017; Foerstl *et al.*, 2018). However, only a few studies have addressed information processing problems related to environmental data in supply chains (Dahlmann and Roehrich, 2019; De Stefano and Montes-Sancho, 2024; Vieira *et al.*, 2024). Accordingly, there is a significant research gap regarding how sustainability-related uncertainties emerge in supply chains and how organizations can implement information processing mechanisms to reduce them. This situation requires further empirical investigation into how organizations can identify the sources of these indirect environmental impacts and develop effective methods for their measurement, disclosure, and mitigation. Addressing this gap is essential, because increasing transparency and accuracy in sustainability-related reporting improves sustainability-related risk management and supports the broader decarbonization transition demanded by regulators and stakeholders. The exploration of these dynamics is also critical for understanding how organizations can strengthen their capacity to build resilience in climate-affected supply chains. Moreover, this aligns with calls to consider social-ecological resilience in supply chain management (Wieland, 2021), recognizing environmental and organizational systems' interdependence in adapting to environmental challenges.

1.3 Research objectives

This dissertation addresses the research gaps by investigating how digitalization affects risk management and resilience in modern supply chains. In doing so, it contributes to the literature on the effects of digitalization on managing risks and disruptions in supply chains. Specifically, this dissertation provides new insights into the mechanisms through which organizations can leverage digital technologies and technology-related practices to build resilience against diverse types of risks and disruptions. This aim is achieved through a structured examination across four publications. The main research question of this dissertation is as follows:

How does digitalization affect organizations' capacity to manage risks and increase resilience in their supply chains?

The main research question is addressed across four publications included in this dissertation, through three separate sub-questions, as illustrated in Table 1. The first sub-question is as follows:

Sub-question 1: How does procurement digitalization impact supply chain resilience?

Procurement digitalization is defined as the use of digital technologies to support procurement-related activities, such as sourcing, contracting, and supplier management (Srai and Lorentz, 2019). In this dissertation, it is understood as a focused subset of broader supply chain or firm-level digitalization, emphasizing the upstream interface between organizations and their suppliers. Digitalization introduces many opportunities to improve procurement efficiency. In particular, the ability to integrate data, share information, and digitalize procurement processes can increase the effectiveness of managing risks related to the upstream supply chain. Publication I addresses this notion by drawing from the organizational information processing theory. This study presents an empirically validated model illustrating how different elements of procurement digitalization influence risk management and resilience in organizations' supply chains.

To better understand how organizations can manage risk and resilience in externally acquired technology services, the second sub-question is posed:

Sub-question 2: How can organizations manage risk and resilience during the process of acquiring and implementing technology solutions?

External acquisition and management of technology services are fundamental aspects of digitalization in supply chains. As supply chains increasingly rely on data-driven systems and outsourced technological services, understanding risk factors and strategies to manage them is critical for ensuring operational continuity. Publication II investigates this issue through a single case study in the financial services sector, examining sequential risk management routines across different stages of the procurement process. This study provides insights into how organizations can improve their risk management practices to mitigate disruptions and enhance the performance and continuity of externally produced IT services. Extending the scope of Sub-question 2, Publication IV focuses on ensuring sustainability in ICT service supply chains. By addressing challenges, drivers, and practices associated with integrating sustainability into the procurement of technology services, Publication IV highlights how sustainability-related risks—such as regulatory non-compliance, reputational issues, or social and environmental impacts—can be managed alongside traditional risk management practices. Together, these publications contribute to a holistic understanding of how organizations can manage resilience in the procurement and implementation of technology services to ensure their effective and sustainable use in supply chain operations.

To investigate how organizations can better manage emissions-driven environmental sustainability risks through information processing in their supply chains, the third sub-question is posited:

Sub-question 3: How can information processing address challenges associated with different sources of uncertainty that hinder sustainability in supply chains?

The design and governance of supply chains with respect to environmental considerations have significant implications for sustainability. In particular, indirect greenhouse gas

(GHG) emissions have emerged as a critical risk consideration in supply chains, since these types of emissions are difficult to measure and disclose, and are a primary driver of climate change-induced disruptions. These sustainability challenges can lead to disruptions at the ecosystem level, and cascade into severe reputational and financial risks in supply chains (Blanco, 2021). Addressing these risks requires organizations to leverage digital technologies and data-driven practices to increase their information processing capabilities to better manage emissions across supply chains. Publication III aims to improve understanding of how organizations can address the challenges of measuring, disclosing, and reducing GHG emissions in supply chains. Specifically, it investigates (1) information processing needs that hinder activities related to the measurement and disclosure of environmental sustainability in supply chains, and (2) information processing mechanisms that can help overcome these challenges. By doing so, Publication III advances knowledge of how organizations and their supply chains can mitigate sustainability-related risks emerging from GHG emissions through data-driven practices.

Table 1: Overview of the publications, research objectives, questions, and methodologies

	Publication I	Publication II	Publication III	Publication IV
Title	The impact of procurement digitalization on supply chain resilience: empirical evidence from Finland	The role of risk management practices in IT service procurement: A case study from the financial services industry	Understanding the systematic sources of uncertainty for the management of GHG emissions in supply chains	Sustainability meets service procurement: a case study in the ICT service sector
Main objective	Investigate how procurement digitalization influences supply chain resilience, focusing on data analytics, information sharing, and digital process maturity.	Examine how risk management practices in IT service procurement influence service performance and mitigate risks, specifically in a case study of the financial services industry.	Explore how uncertainty related to Scope 3 emissions affects information processing in the steel supply chain.	Investigate the challenges, drivers and practices related to managing the sustainability of ICT service suppliers.
Research questions (RQs) in the publications	**RQ1**: How does procurement digitalization impact supply chain resilience?	**RQ2a**: What are the major risk factors related to the procurement of IT services? **RQ2b:** What practices are used to manage risks during the service procurement process?	**RQ3**: How do different sources of uncertainty hinder the measurement and reporting of GHG emissions in SCs?	**RQ1**: What types of challenges and drivers influence the implementation of sustainable procurement in ICT service supply chains? **RQ2**: What kinds of practices are used to ensure the sustainability of ICT service suppliers?
Methodology	Quantitative, cross-sectional survey, Partial Least Squares (PLS) path modeling	Qualitative, single-case study, semi-structured interviews, and secondary data analysis	Qualitative study, semi-structured interviews	Qualitative, single-case study, semi-structured interviews, and secondary data analysis
Theoretical lens	Organizational information processing theory	Practice-based view and supply chain practice view	Organizational information processing theory	-
Empirical context	Finnish manufacturing and retail sectors (147 firms)	Financial services company and its key IT service providers (14 interviews)	Steel industry across 12 European organizations (16 interviews)	Financial services company and its key IT service providers (14 interviews)
RQs addressed in this dissertation	Sub-question 1	Sub-question 2	Sub-questions 1 and 3	Sub-question 2

1.4 Structure of the dissertation

This dissertation is structured as follows. Chapter 1 contains the introduction, background, and research gaps, and presents the research objectives of this dissertation. Chapter 2 provides the conceptual and theoretical background by discussing the key concepts and the organizational theories underlying this dissertation. Chapter 3 explains the research philosophy, methodology, and research quality considerations for the studies included in this dissertation. Chapter 4 summarizes the main results reported in each of the four publications. Finally, Chapter 5 presents the discussion and conclusions, elaborates on this dissertation's contributions, acknowledges its main limitations, and offers potential avenues for future research.

2 Conceptual and theoretical background

2.1 Defining supply chains and supply chain management

Traditional management research has considered the coordination activities, resources and capabilities within an organization to be essential for maintaining performance and achieving competitive advantage (Galbraith, 1974; Barney, 1991; Teece *et al.*, 1997). However, since global outsourcing becoming the trend, scholars increasingly recognized that the type and extent of inter-organizational interactions are also crucial aspects when attempting to understand organizational behaviours and performance (Bensaou and Venkatraman, 1995; Dyer and Singh, 1998; Carter *et al.*, 2015). Therefore, for the better part of the last thirty years research has started to increasingly emphasize the integration of processes, practices and capabilities across organizational boundaries to better understand the factors leading performance variation among organizations (Lambert and Cooper, 2000). This notion has subsequently given emergence to research dedicated to supply chains and how to manage them.

A supply chain can be understood as the network of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Mentzer *et al*. (2001) define a supply chain as "*a set of three or more entities directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer*." Supply chain research typically attempts to study the organizational structures, management characteristics and decision-making interactions between either two organizations (such as a buyer and a supplier dyad) (Harland *et al.*, 2003), three organizations (such as supplier-buyer-customer triad) (Wynstra *et al.*, 2015; Suurmond *et al.*, 2022) and extended networks of organizations and their stakeholders spanning across horizontal and vertical tiers in the supply chain network (Chen and Paulraj, 2004; Kähkönen, 2014; Carter *et al.*, 2015; De Stefano and Montes-Sancho, 2024). Some research has also conceptualized supply chains from the complex systems perspective, in which supply chain actors dynamically interact, adapt, and co-evolve in response to changes in their environment, resulting in emergent behaviours that may be fully predicted or controlled with traditional management approaches (Choi *et al.*, 2001; Wieland, 2021).

A classical definition for supply chain management refers to it as "the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers" (Cooper *et al.*, 1997). In practice, this involves coordination and integration of material, information, financial and service flows across the supply chain network structure, with the aim of managing co-dependent business processes to reduce costs and enhance overall performance (Lambert and Cooper, 2000; Flynn *et al.*, 2010). In this context, it is also important to note that most supply chains exist in a global setting, in which the management of supply chain processes and collaboration across supply chain partners may be complicated by geographical, cultural and socioeconomic distance (Craighead *et al.*, 2007; Busse *et al.*, 2017; Foerstl *et al.*, 2018). For these reasons, the scope of supply chain management has evolved significantly, expanding from a focus on optimizing logistics and operations to encompassing a broader strategic role, including risk management, (Manuj and Mentzer, 2008) business continuity and resilience (Sheffi and Rice, 2005; Pettit *et al.*, 2010), sustainability (Seuring *et al.*, 2008), and the use of digital technologies (Ivanov *et al.*, 2019; Yang *et al.*, 2021).

2.2 Understanding uncertainty, risks, and disruptions in supply chains

Uncertainty, risk, and disruptions are fundamental concepts to understanding how organizations can effectively manage their supply chains in turbulent environments. These constructs are interconnected yet distinct. The purpose of this section is to provide a detailed examination of each concept. An overview of uncertainty, supply chain risk and supply chain disruption are presented in Table 2.

Table 2: Uncertainty, supply chain risk and supply chain disruption

Concept	Definition	Key distinctions	References
Uncertainty	A state in which the outcomes of events or future conditions are unknown and unpredictable due to incomplete or imperfect information.	Uncertainty cannot be measured or predicted (unknown unknowns). Can lead to positive or negative outcomes	(Milliken, 1987; van der Vorst and Beulens, 2002; Ho *et al.*, 2015)
Supply chain risk	The potential events or circumstances that could adversely affect the flow of goods, services, finance or information within a supply chain.	Risks are assumed to be measurable and can be identified, assessed, mitigated and monitored. Typically focus on adverse events with quantifiable likelihood and impact.	(Manuj and Mentzer, 2008; Tummala and Schoenherr, 2011; Fan and Stevenson, 2018)
Supply chain disruption	Unanticipated events that interrupt the normal flow of goods, services, or information in the supply chain, often causing significant operational and financial impacts.	Supply chain disruptions are actualized risks or other disruptive events. They result in immediate or prolonged consequences like operational delays or failures.	(Hendricks and Singhal, 2005; Kleindorfer and Saad, 2005; Sheffi and Rice, 2005; Craighead *et al.*, 2007; Ponomarov and Holcomb, 2009)

2.2.1 Uncertainty

Uncertainty is an essential concept related to the management of organizations and the supply chains they are embedded in. Although management literature seems to be often ambiguous about the distinction between uncertainty and risk, it is nevertheless to crucial recognize that uncertainty refers generally to situations where future outcomes are unpredictable and may not be measured or predicted with accuracy (Milliken, 1987). Uncertainty represents incomplete information about future events, whether they are positive or negative. As such, it is connected to unexpected positive outcomes, but also to risks and disruptions due to the inability of decision makers to proactively evaluate probability and effects of decisions and adverse developments in the operating environment (Zsidisin, 2003). Indeed, uncertainty has been perceived as an innate property of the risk construct (Yates and Stone, 1994).

In the supply chain context, van der Vorst and Beulens (2002) define uncertainty as "*decision making situations in the supply chain in which the decision maker does not know definitely what to decide as he is indistinct about the objectives; lacks information about (or understanding of) the supply chain or its environment; lacks information processing capacities; is unable to accurately predict the impact of possible control actions on supply chain behavior; or, lacks effective control actions (non-controllability)*". Research shows that uncertainty in supply chains may originate from various sources. These sources typically arise either internally or externally (Trkman and McCormack, 2009). Internal sources of uncertainty include, for example, lack of information about contingencies in the supply chain (such as communication bottlenecks or supplier-related issues), misalignment between departments, or variability in production processes (van der Vorst and Beulens, 2002). Externally, uncertainty may arise from unpredictable shifts in market demand, geopolitical events, or natural disasters that disrupt the supply chain's flow (Trkman and McCormack, 2009; Heckmann *et al.*, 2015). Other exemplary and context-specific conceptualizations for the sources of uncertainty include supply, demand and process uncertainty (van der Vorst and Beulens, 2002), environmental uncertainty (Milliken, 1987; Bensaou and Venkatraman, 1995), task uncertainty, source and supply chain uncertainty (Busse *et al.*, 2017; Foerstl *et al.*, 2018), technological uncertainty (Stock and Tatikonda, 2008), and partnership uncertainty (Bensaou and Venkatraman, 1995; Premkumar *et al.*, 2005).

2.2.2 Supply chain risks

Risk is an old concept and has been broadly discussed in cross-disciplinary settings. Although many have noted risk to be often vaguely defined and context-specific (e.g., Heckmann *et al.*, 2015), it can be commonly understood as the potential for loss, uncertainty or probability of a loss and the significance of such a loss (Yates and Stone, 1994). In line with this, Mitchell (1995) characterizes risk as follows:

$$\text{Risk} = \text{Probability}\ (\text{Loss}_n) \times \text{Impact}\ (\text{Loss}_n)$$

For the purposes of managing organizations, the understanding of risk is context-dependent and perception-based, meaning that adverse events and probabilities related to them should be determined from the perspective of the organizational goals and the factors that may hinder their achievement. Often the primary goal of an organization is to stay competitive, which prioritizes risks related to demand and service levels. Considering this, researchers have extended the classification of risk by attributing different contextual elements to it, for example, the granularity of loss types, ranging from financial losses to reputational damage, legal liabilities, operational inefficiencies, customer safety and even psychological and social consequences (Jacoby and Kaplan, 1972; Zsidisin, 2003; Manuj and Mentzer, 2008). The evaluation of risk, therefore, often involves not just the likelihood of a negative event but also its potential impact on multiple dimensions of organizational performance.

Similarly, research on supply chain risk has provided many different conceptualizations, definitions and typologies (Manuj and Mentzer, 2008; Heckmann *et al.*, 2015; Ho *et al.*, 2015). A general definition for supply chain risk refers to it as the probability and impact of unexpected macro or micro level events or conditions that negatively affect any part of a supply chain, leading to operational, tactical, or strategic level failures (Ho *et al.*, 2015). The literature on supply chain risk presents numerous different types of classifications. For example, supply chain risks may be classified based on their source and impact, such as demand risk, which stems from unpredictable fluctuations in customer demand, leading to imbalances between supply and demand (Chopra and Sodhi, 2004). Another common element is supply risk, which occurs when supplier failures or disruptions in the upstream supply market result in delays or shortages that hinder the ability of the purchasing firm to meet customer demand (Zsidisin, 2003). Furthermore, operational and process risks are critical elements of supply chain risk, arising from internal supply chain inefficiencies, such as production breakdowns, which can disrupt the flow of goods (Heckmann *et al.*, 2015). Table 3 offers a summary of the literature on the most prominent supply chain risks.

Table 3: Exemplary typology for understanding supply chain risk

Category	Definition	Examples	References
Demand risk	The risk of unpredictable fluctuations in customer demand, causing supply-demand imbalances.	Sudden demand surges or drops, inaccurate demand forecasting, changing customer preferences.	(Chopra and Sodhi, 2004; Christopher and Peck, 2004; Heckmann *et al.*, 2015)
Supply risk	Risks related to inbound supply, caused by supplier failures or supply market disruptions in the upstream of the focal company.	Supplier bankruptcy, quality issues, raw material shortages, delivery delays, long lead times.	(Zsidisin, 2003; Christopher and Peck, 2004)
Operational, control and process risk	Risks arising from internal supply chain operations, including production, logistical failures, and insufficient control or oversight over processes.	Equipment breakdowns, labour strikes, inefficiencies in production processes, poor inventory management and weak governance mechanisms.	(Christopher and Peck, 2004; Heckmann *et al.*, 2015)
Transportation risk	Risks associated with the transportation and distribution of goods.	Delays, accidents, port strikes, rising fuel costs, natural disasters disrupting transport routes.	(Spekman and Davis, 2004; Blackhurst *et al.*, 2008)
Financial risk	Risks associated with financial instability or economic disruptions affecting supply chain operations.	Currency fluctuations, interest rate changes, supplier financial distress, liquidity shortages.	(Manuj and Mentzer, 2008; Heckmann *et al.*, 2015)
Environmental risk	Risks stemming from environmental factors, including natural disasters and regulatory changes.	Earthquakes, floods, extreme weather conditions, changing environmental law, regulations or sociopolitical conditions.	(Chopra and Sodhi, 2004; Christopher and Peck, 2004; Kleindorfer and Saad, 2005)
Geopolitical risk	Risks associated with political instability or government policy changes that affect supply chains.	Trade wars, tariffs, sanctions, civil unrest, changes in government regulations affecting imports/exports.	(Roscoe *et al.*, 2020; Fan *et al.*, 2024)
Cybersecurity risk	Risks associated with cyberattacks or IT system failures that can disrupt supply chain operations.	Data breaches, ransomware attacks, IT infrastructure failures, system downtime.	(Spekman and Davis, 2004; Blackhurst *et al.*, 2008; Ghadge, Weiß, *et al.*, 2020)
Reputational risk	Risks that arise when negative perceptions about a company or its products damage stakeholder trust.	Product recalls, unethical supplier practices, human rights violations.	(Harland *et al.*, 2003; Spekman and Davis, 2004)
Technological risk	Risks associated with technology failure or rapid technological change.	IT system crashes, technology obsolescence, delays in adopting new technologies, and compatibility issues.	(Chopra and Sodhi, 2004; Blackhurst *et al.*, 2008)
Regulatory risk	Risks arising from non-compliance with government laws and regulations affecting supply chain operations.	Non-compliance with trade regulations, environmental standards, labour laws, or product safety requirements.	(Blackhurst *et al.*, 2008; Wagner and Bode, 2008)
Sustainability risk	Risks related to social and environmental issues that may negatively impact supply chain sustainability.	Failure to meet environmental or ethical standards, use of non-renewable resources, forced labour, carbon emissions.	(Carter and Rogers, 2008; Seuring and Müller, 2008; Giannakis and Papadopoulos, 2016; Kähkönen *et al.*, 2023)

Moreover, with the increasing focus on sustainability, sustainability-related risks are becoming more prominent in both strategic management and supply chain research. Sustainability risks can stem from environmental regulations, stakeholder pressures, or ethical considerations, and they are increasingly critical for long-term organizational survival (Carter and Rogers, 2008; Giannakis and Papadopoulos, 2016). Organizations that fail to account for these risks face not only financial losses but also reputational damage and regulatory penalties. One of the significant aspects of sustainability risks within supply chains is social sustainability, which refers to the management of social issues such as labor rights, working conditions, and community impacts throughout the supply chain (Seuring and Müller, 2008; Awaysheh and Klassen, 2010). Another important driver of sustainability-related risks is climate change, which has introduced new complexities for supply chain operations. Climate-related disruptions, such as extreme weather events, resource scarcity, and shifting regulatory landscapes, expose organizations to multiple operational risks, including logistics and geopolitical considerations (Sodhi and Tang, 2021). In particular, the management of greenhouse gas emissions has become a central focus of risk management, as regulatory bodies and stakeholders increasingly demand transparency and accountability in carbon reporting (Vieira *et al.*, 2024). Scope 3 emissions, which account for the indirect emissions generated across the supply chain, pose a unique challenge due to their complexity and the fragmented nature of data across multiple tiers of suppliers (Dahlmann and Roehrich, 2019; Ellram and Tate, 2024; Vieira *et al.*, 2024). For example, the lack of accurate and standardized emissions data may create significant uncertainty, and potentially lead to reputational damage, regulatory non-compliance, and increased costs associated with mitigation efforts.

2.2.3 **Supply chain disruptions**

Supply chain disruptions refer to unanticipated events or conditions that interrupt the normal flow of goods, services, or information in a supply chain, often leading to adverse operational and financial consequences (Kleindorfer and Saad, 2005; Craighead *et al.*, 2007). In other words, supply chain disruptions manifest as decreased supply chain performance (Sheffi and Rice, 2005) and may negatively affect the valuation and profitability of the firm (Hendricks and Singhal, 2005). While risks are defined as potential adverse events that can be anticipated and managed to varying degrees, disruptions are the actualization of known or unknown risks, resulting in immediate or prolonged interruptions to supply chain activities (Ponomarov and Holcomb, 2009). This distinction is important, as disruptions signify that risk management strategies may have failed to mitigate certain risks, necessitating other capabilities or strategies to manage them, such as resilience and continuity management.

Following the typology of supply chain risk (Table 3), disruptions can be categorized based on similar sources or triggers. Disruptions are understood to originate either externally or internally to the supply chain, taking place in the upstream or downstream (Ponomarov and Holcomb, 2009; Blackhurst *et al.*, 2011). External disruptions typically originate from factors beyond the organization’s control, such as natural disasters, geopolitical events, or economic crises, while internal disruptions stem from within the organization or its supply chain partners, such as process breakdowns, labour strikes, or system failures (Kleindorfer and Saad, 2005; Heckmann *et al.*, 2015). Research highlights the severity and duration of supply chain disruptions as key factors in assessing their overall impact. Hendricks and Singhal (2005) found that severe disruptions not only impair short-term operational performance but also have lasting effects on stock prices, market share, and profitability. Disruptions often also propagate through supply chains due to inherent co-dependencies in business relationships, potentially amplifying the initial shock and affecting multiple tiers of suppliers, distributors, and customers (Hallikas *et al.*, 2004; Dolgui *et al.*, 2018). This implies the interconnectedness and interdependencies between organizations can make disruptions particularly severe. For example, disruptions can create bullwhip effects, in which minor fluctuations or delays in one part of the supply chain lead to magnified issues in other parts (Lee *et al.*, 1997). Similarly, the COVID-19 pandemic illustrated how a global health crisis could disrupt entire industries and supply chains, demonstrating the need for robust contingency planning and adaptive capabilities (Van Hoek, 2020). Therefore, managing disruptions is a complex challenge, as the full impact may not be immediately visible but can unfold over time, affecting both upstream and downstream supply chain partners.

2.3 Supply chain risk management

Supply chain risk management has become a crucial area of focus in both academic research and industry practice due to the growing complexity-driven vulnerabilities of modern supply chains. Fan and Stevenson (2018) define supply chain risk management as "*the identification, assessment, treatment, and monitoring of supply chain risks, with the aid of the internal implementation of tools, techniques, and strategies, and of external coordination and collaboration with supply chain members, so as to reduce vulnerability and ensure continuity coupled with profitability, leading to competitive advantage*." This definition emphasizes two key components of effective risk management: the internal implementation of risk management strategies and external collaboration with supply chain partners to manage supply chain risks and disruptions.

Supply chain risk management is typically viewed as a dynamic and multi-phase process, structured around four main steps: risk identification, risk assessment, risk mitigation, and risk monitoring (Hallikas *et al.*, 2004; Tummala and Schoenherr, 2011). Each stage plays a critical role in ensuring that supply chains remain capable of mitigating and responding to supply chain risks and disruptions. Research shows that in addition to implementing an internal supply chain risk management practices, collaborative approaches between supply chain partners are required to better prepare for risks and manage disruptions in the supply chain (Ho *et al.*, 2015).

Scholars often discuss supply chain risk management as a collaborative activity, however, much of the research insights for risk management techniques have remained at the organizational level. Others have put more emphasis on its inter-organizational nature

(Ho *et al.*, 2015; Friday *et al.*, 2018). They argue that the management of supply chain risks is an inherently collaborative process, which requires coordination and information sharing across multiple stakeholders within the supply chain (Fan *et al.*, 2017). Effective supply chain risk management cannot be achieved in isolation, as risks often emerge from interdependencies between suppliers, manufacturers, logistics providers, and other partners. Thus, collaboration across organizational boundaries is crucial to gain a comprehensive view of potential risks and develop joint strategies for managing them (Jüttner et al., 2003; Fan and Stevenson, 2018). Collaborative risk management requires organizations to engage with supply chain partners, such as suppliers and logistics service providers, to align on risk management objectives, share information, standardize and integrate processes, and invest in collaborative performance systems (Friday *et al.*, 2018). This is particularly important for managing shared risks—those that may catastrophically affect the entire supply chain—such as natural disasters, geopolitical risks, or strikes (Dolgui *et al.*, 2018). This also necessitates the consideration of factors such as supplier governance, trust, and mutual commitment, which are essential for fostering effective collaboration (Fan *et al.*, 2017). Next, the key steps of a typical supply chain risk management process are discussed, as illustrated in Figure 1.

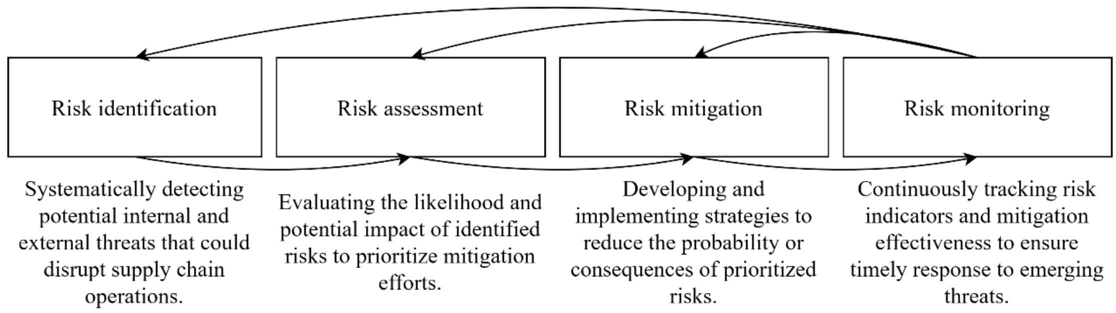


Figure 1: Supply chain risk management process (adopted from Hallikas *et al*., 2004; Tummala and Schoenherr, 2011; Fan *et al*., 2018).

2.3.1 Risk identification

Risk identification involves systematically recognizing and classifying potential risks that could affect the supply chain, both from internal and external sources (Fan and Stevenson, 2018). Risks may originate from various areas, such as operational inefficiencies, supply market failures, transportation disruptions, geopolitical events, or natural disasters, as illustrated in Section 2.2.2, Table 3. Risk identification must also consider digitalization-related risks such as cyber threats and sustainability-related risks, such as the climate change, which are increasingly critical in contemporary supply chains (Ghadge, Weiß, *et al.*, 2020; Ghadge, Wurtmann, *et al.*, 2020). This is a particularly critical first step, because only identified risks can be mitigated through risk management practices. Risk identification may include multiple approaches, for example, mapping the supply chain, using checklists, event tree analysis, and failure mode and effect analysis (Tummala and Schoenherr, 2011).

2.3.2 **Risk assessment**

Once risks have been identified, they must be evaluated in terms of their likelihood of occurrence and the potential impact on the supply chain. For this reason, risk identification and assessment are often activities performed together sequentially. This step involves formal, informal, quantitative and qualitative assessments to rank risks by their potential severity and to prioritize mitigation efforts accordingly (Zsidisin *et al.*, 2004). Risk probabilities are often evaluated subjectively, for example, through expert panel or qualitative measurement scales (Hallikas *et al.*, 2004; Tummala and Schoenherr, 2011). Negative impacts can be understood, for example, through the measurement of damage to assets, income losses, service levels, cost increases, delays or personal injuries (Tummala and Schoenherr, 2011). Moreover, suppliers may be requested to, for example, self-complete scorecards and conduct self-audits. Supply chain risk assessment often takes into account both the vulnerability of the supply chain and the criticality of specific nodes or links within the network, allowing the assessment of dependencies between different risks and their outcomes (Wagner and Bode, 2008). An important aspect of risk assessment is that it allows prioritization for mitigating perceived risks (Fan and Stevenson, 2018).

2.3.3 **Risk mitigation**

Risk mitigation refers to the development and implementation of response strategies aimed at reducing the likelihood of risks materializing or minimizing their impact when they do occur (Sodhi *et al.*, 2012). The purpose of risk mitigation is not necessarily the complete elimination of the risk, but rather, reducing its severity to an acceptable level in contrast to the expected costs of mitigation measures (Tummala and Schoenherr, 2011). Research has identified several risk management strategies to address different types of risks, which are illustrated in Table 4.

Table 4: An overview of risk mitigation strategies in the supply chain, adapted from Manuj and Mentzer (2008), Ho *et al*., (2015) and Fan and Stevenson (2018)

Risk mitigation strategy	**Definition**	**Examples**	**Use cases**
Risk avoidance	Modifying supply chain processes or eliminating activities that expose the firm to unacceptable risks.	Avoiding high-risk suppliers, discontinuing production in a politically unstable region, delaying market entry.	Used when a risk has potentially severe consequences that are deemed unacceptable.
Risk postponement	Delaying certain actions or decisions until more information is available or conditions stabilize.	Postponing large-scale investments in new technology until there is regulatory clarity.	Ideal for managing risks with high uncertainty or ambiguity where future outcomes can be better predicted with more time.
Risk hedging	Creating redundancy or alternative options, such as having multiple suppliers or safety stock, to mitigate the impact of supply disruptions.	Maintaining a diverse supplier base, dual sourcing, stockpiling critical raw materials.	Commonly used in supply chains to safeguard against low probability and high impact supply disruptions or volatile markets.
Risk control	Implementing measures, such as quality checks or stricter process controls, to manage and minimize operational risks.	Instituting frequent quality audits, implementing just-in-time (JIT) inventory systems with strict controls.	Effective for managing operational risks or process inefficiencies within the supply chain.
Risk sharing/transfer	Shifting the financial impact of risk to a third party through mechanisms such as contractual clauses, insurance or outsourcing.	Purchasing supply chain insurance, outsourcing logistics to third-party providers.	Often used to manage risks that are difficult for the company to control directly, such as natural disasters or transportation risks.
Risk taking	Accepting certain risks as a calculated decision to achieve higher returns, often after other risk management strategies have been considered.	Entering a new market despite geopolitical risks, launching a new product with uncertain demand forecasts.	Typically employed when potential rewards outweigh the identified risks, especially in innovation-driven industries.

2.3.4 Risk monitoring

The final step of the risk management process involves continuously tracking identified risks and emerging threats. This is often closely linked to risk assessment methods (Norrman and Jansson, 2004; Fan and Stevenson, 2018), and can be used for the continuous improvement of assessment and mitigation methods (Tummala and Schoenherr, 2011). Monitoring ensures that risk management strategies remain relevant and effective in light of changing circumstances. Ongoing risk monitoring can involve, for example, the monitoring of risk through key performance indicators and performance measurement systems (Fan and Stevenson, 2018) and the use of other business data systems to track risk-related information regarding the supply chain (Tummala and Schoenherr, 2011). Risk monitoring is especially important when risk levels are high or risks remain unmitigated (Norrman and Jansson, 2004).

2.4 Supply chain resilience

Supply chain resilience is a multifaceted concept with cross-disciplinary roots. Scholars have often taken different views on what supply chain resilience means and how it should be operationalized in research and practice. Here, two principal conceptualizations for supply chain resilience are discussed: (1) traditional, engineering-oriented resilience and (2) social-ecological view on resilience.

2.4.1 Traditional view of supply chain resilience

Ponomarov and Holcomb (2009) define supply chain resilience as "*the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.*" This definition is particularly useful from an operational standpoint, in which supply chain resilience is often conceptualized through a combined capacity to resist and recover when disruptions take place (Sheffi and Rice, 2005). Resistance refers to the supply chain's ability to avoid or minimize the impact of disruptions through proactive strategies, such as risk mitigation and redundancy. Recovery, on the other hand, involves the ability to restore operations and performance levels after a disruption has occurred. Similarly, research has shown that supply chain resilience can be further differentiated into specific dimensions. For example, Ali *et al*. (2017) conceptualize these dimensions as (1) readiness (pre-disruption), (2) responsiveness (during-disurption), and (3) recovery and/or growth (post-disruption). Achieving resilience requires unique proactive and reactive strategies for each dimension, such as the ability to anticipate disruptions, adapt and respond to them, and the ability to learn post-disruption (Ali *et al.*, 2017). This conceptualization is further illustrated in Figure 2, which displays the stages of a supply chain disruption.

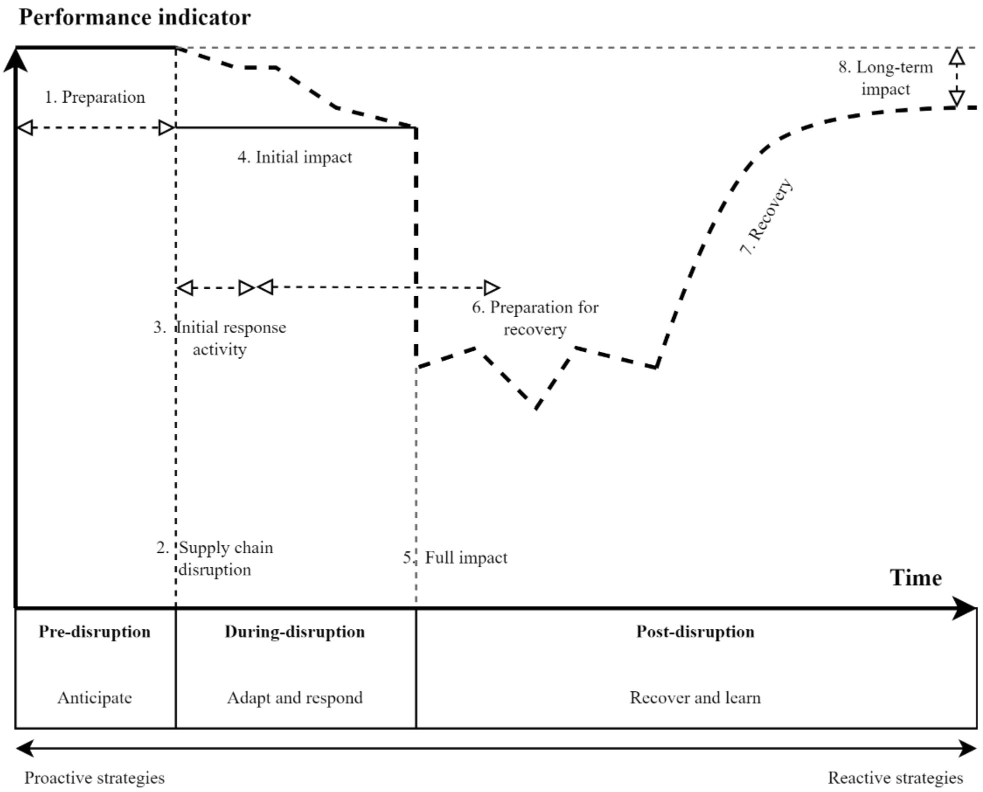


Figure 2: Understanding resilience through the stages of a supply chain disruption (adapted from Sheffi and Rice, 2005; Ali *et al*. 2017)

Research has also found many capabilities that support achieving resilience, such as supply chain re-engineering, collaboration, agility, risk management culture, visibility, and flexibility (Christopher and Peck, 2004; Hohenstein *et al.*, 2015). Practical examples to increase such capabilities include flexible sourcing, using inventory buffers for safety stocks, and strong communication channels between supply chain partners (Christopher & Peck, 2004; Tang, 2006). These practices enable organizations and their supply chains to manage risks early and respond to disruptions more effectively (Pettit *et al.*, 2010). However, as noted by Hohenstein *et al*. (2015) and Holgado *et al*. (2024), such a definition lacks emphasis on post-disruption improvement of the supply chain through learning, growth and transformation. Therefore, integrating learning-oriented post-disruption feedback-loops into disruption management processes can be considered vital to maintaining resilience in dynamic supply chain environments (Blackhurst *et al.*, 2011).

2.4.2 Social-ecological view of supply chain resilience

More recently, resilience in supply chains has been increasingly integrated into the social-ecological systems perspective, in which resilience is viewed as the capacity of a system to absorb shocks, adapt, and transform in the face of changing environmental and economic conditions (Wieland and Durach, 2021). This holistic perspective emphasizes that resilience is not merely about bouncing back to a pre-disruption state, but also about adapting to new conditions and emerging stronger from disruptions (Ali *et al.*, 2017). In other words, social-ecological resilience departs from static, closed-system thinking and assumes complex, open, and emergent system properties. This view is more dynamic, emphasizing that supply chains must not only survive disruptions but also learn and evolve from them through transformation. These assumptions are in line with Holling (2001), who introduced resilience in ecological systems, and proposed that resilience is not just about returning to equilibrium but adapting to external changes in ways that ensure long-term sustainability. Applying this view to supply chains, resilience is assumed to be a dynamic, rather than a static concept, involving holistic and interpretivist, approaches to understanding cross-level linkages between hierarchical social-ecological systems, in which supply chains are embedded in (Wieland, 2021).

In close alignment with the holistic perspective, the concept of supply chain resilience has evolved to include sustainability considerations. This evolution is grounded in two primary factors. Firstly, sustainability has emerged as a critical performance indicator in supply chains, driven by regulatory pressures and also by changing consumer expectations and corporate social responsibility commitments (Carter and Rogers, 2008). As stakeholders increasingly prioritize environmental and social performance, organizations must proactively manage sustainability-related risks that stem from both their internal operations and their supply chain partners. These risks may involve environmental issues such as resource scarcity, carbon emissions, and waste management, as well as social issues such as labor practices and community impact (Giannakis and Papadopoulos, 2016; Kähkönen *et al.*, 2023). While such sustainability-related risks may not cause direct operational performance disruptions, the reconfiguration of supply chain activities, for example, due to suppliers' activities causing reputation-losses, may lead to negative supply chain performance implications. Consequently, resilience in this context extends beyond mere operational continuity to ensuring that supply chain practices are sustainable, ethically responsible, and capable of meeting long-term environmental and social goals (Giannakis and Papadopoulos, 2016).

Secondly, sustainability considerations—particularly those related to environmental impact—have been closely linked to climate change and the disruptions to environmental ecosystems in which supply chain networks are embedded. Climate change introduces additional layers of uncertainty and risk for supply chains, such as extreme weather events, rising sea levels, and shifts in resource availability (Intergovernmental Panel on Climate Change, 2023; Matos *et al.*, 2024). These environmental disruptions can severely impact global supply chains by causing sudden interruptions in the supply of raw materials, damaging critical infrastructure, or altering production capacities. Thus, resilience in today's supply chains requires firms to adapt to and mitigate the impacts of these environmental challenges to ensure both short-term recovery and long-term sustainability (Pettit *et al.*, 2010; Wieland and Durach, 2021).

2.5 Digitalization and supply chain risk management

Digital transformation has emerged as a transformative force in modern supply chains, reshaping business models and the way organizations manage processes, information, and relationships (Verhoef *et al.*, 2021). Digitalization is a key part of this transformation, defined as the integration of digital technologies into business process management (Srai and Lorentz, 2019; Verhoef *et al.*, 2021), enabling real-time data processing, enhanced visibility, and improved decision-making across the supply chain. Research suggests that a vast number of digital technologies are associated with digitalization, such as big data, data analytics, IoT devices, blockchain, cloud computing, and artificial intelligence (Zekhnini *et al.*, 2021). Procurement digitalization, defined as the use of digital technologies to improve procurement-related activities (Srai and Lorentz, 2019), is an important subset of digital transformation within organizations. It focuses specifically on the upstream domain of supply chain management, including activities such as the automation of transactions, understanding supplier capabilities, maintaining relationships with suppliers, and the overall improvement of processes. As such, it represents a more narrowly scoped but strategically significant area within broader supply chain or firm-level digitalization. Research dedicated to this area of study has only recently begun to emerge (Kosmol *et al.*, 2019; Srai and Lorentz, 2019; Seyedghorban *et al.*, 2020; Lorentz *et al.*, 2021; Herold *et al.*, 2023), and still lacks both sufficient conceptualizations and empirical research. However, an important consideration for procurement digitalization is the effective use of procurement-related data for improved decision-making (Handfield *et al.*, 2019), which can be achieved through a combination of basic and novel technologies (Srai and Lorentz, 2019).

Recent studies show that such technology-driven improvements may have a profound impact on the management of risk and disruptions in supply chains by enhancing both preventive and responsive capabilities (Fischer-Preßler *et al.*, 2020). An organization's ability to be more proactive in its risk management due to use of novel technologies has also implications for supply chain resilience. For example, technologies such as the IoT and blockchain facilitate the seamless exchange of real-time data across supply chain partners, which ay help in monitoring and innovation-related activities (Warner and Wäger, 2019). Similarly, an organization's capacity to use data analytics enables them to detect and respond to disruptions faster than in the absence of technologies that support it (Dubey *et al.*, 2021). Studies show that digital technologies enhance supply chain resilience by enabling real-time visibility, predictive analytics, and rapid decision-making (Ivanov *et al.*, 2019). Also, many recent studies have produced empirical evidence of the positive association of digitalization and supply chain resilience (Zouari *et al.*, 2021; Harju *et al.*, 2023; Zhao *et al.*, 2023). Digitalization allows such benefits, for example, through improved collaboration and information sharing between supply chain partners (Ghadge, Er Kara, *et al.*, 2020).

Although research shows that digitalization may have a profound influence on organizations' capacity to manage risks and disruptions in the supply chain, implementing technologies and technology-related practices in supply chains remains a complex issue. In practice, most organizations rely on technology outsourcing and procurement of ICT services to increase the digitalization level of their supply chains. This involves the acquisition of critical technology services, such as analytics, cloud computing, cybersecurity solutions, and enterprise software from external vendors to support the management of supply chain operations. Despite potentially improving risk management capabilities, it should be mentioned that digitalization has been found to also increase the susceptibility to technology-related risks in supply chains, such as dependency on technology vendors, implementation and cyber-security risks (Ghadge, Weiß, *et al.*, 2020; Kessler *et al.*, 2022). One of the key challenges of technology outsourcing is the dependency on third-party service providers, which may introduce various risks related to service continuity, hidden costs, and reputational losses (Ellram *et al.*, 2007, 2008; Wynstra *et al.*, 2015). Research highlights that managing these risks requires organizations to adopt robust procurement strategies, such as comprehensive service definitions, strategic supplier assessment and selection, and the implementation of service-level agreements to ensure compliance and performance stability (Ellram *et al.*, 2008; Van Der Valk and Rozemeijer, 2009; Akkermans *et al.*, 2019). Moreover, other types of governance mechanisms, including periodic performance reviews, trust and collaboration with technology service suppliers, may be critical in mitigating potential disruptions in outsourced technologies (Gelderman *et al.*, 2015; Raddats *et al.*, 2017).

2.6 Organizational information processing theory

Organizational information processing theory was developed to understand how uncertainty affects task completion in organizations, and how organizations can implement information processing mechanisms to reduce the negative performance effects of uncertainty (Galbraith, 1974). Information processing is defined as "*the gathering, interpretation and synthesis of information in the context of organizational decision-making*" (Tushman and Nadler, 1978). It therefore focuses on the use and value of information to support decision-making for planning and executing organizational activities, designs and structures. The theory proposes a mechanistic view of organizations, where to goals of the organization is characterised as a global task composed of smaller subtasks assigned to appropriate specialists within the organization. Such task structures can then give rise to interdependencies and coordination problems within the organization, which manifest as increased uncertainty and performance issues. Galbraith (1974, pp. 28-29) argued that integrative mechanisms for processing information are therefore crucial; as task uncertainty increases, decision makers need to process more information during task execution to maintain performance. Because the range of possible strategies is often high and strategies are expected to have differing effectiveness, the primary emphasis of information processing is thus to support *more informed* decision-making related to them. Based on these premises, the theory originally proposed that the design of organizational forms and strategies should be variant to their ability to reduce uncertainty through information processing. Furthermore, organizations must consider the relative costs of alternative strategies when attempting to achieve better information processing performance. An overview of the theory and its key assumptions are provided in Table 5.

The two main strategies to improve information processing, in which optimal fit is to be achieved: (1) reducing the amount of information that needs to be processed and (2) improving information processing capability (Galbraith, 1974). Achieving optimal fit is important, because otherwise an organization will suffer either sub-optimal decision-making due to increased uncertainty or incur costs due to an overmatch of information processing mechanisms — both are assumed to lead to the reduced performance of the organization (Premkumar *et al.*, 2005).

Galbraith (1974) identifies seven distinct mechanisms that allow more efficient information processing, which are divided into hierarchical mechanisms and organizational design strategies. These mechanisms are aimed to reduce the effects of uncertainty by increasing coordination among the members of the organization during the execution of tasks. The hierarchical mechanisms include the implementation of formal rules to reduce the need to process information by improving the coordination of predictable tasks. Similarly, organizations may form hierarchies to reduce information processing needs, allowing higher levels in the organization to oversee and guide task execution of subunits. Output specification is a hierarchical mechanism that streamlines information processing by clarifying the communication related to tasks by establishing expectations for tangible outcomes.

Table 5: Overview of the organizational information processing theory, based on Galbraith (1974), Tushman and Nadler (1978), Bensaou and Venkatraman (1995) Premkumar *et al*. (2005) and Fan *et al*. (2017)

	Information processing at the intra-organizational level	**Information processing at the inter-organizational level**
Dependent variable	Organizational performance, particularly related to task completion.	Interorganizational performance, particularly performance between supply chain partners.
Explanatory variables	Information processing mechanisms aimed at reducing the need or increase the capacity to process information, which reduce uncertainty and its negative effects.	Collaborative information processing mechanisms to manage uncertainty and decision-making-related interdependencies across organizations.
Unit of analysis	The organization and its capacity to process information, manage interdependencies, and maintain task performance.	The supply chain dyad or network, and its information processing capacity, focusing on how organizations collectively process information and manage interdependencies to improve shared performance outcomes.
Key assumptions	Organizations face varying degrees of uncertainty, which may originate from different sources, and performance depends on the ability to align information processing capacity with task complexity. Greater uncertainty requires more information to be processed to maintain performance.	Supply chains face shared uncertainties and interdependencies that require coordinated information processing across multiple firms to achieve collective performance goals. Greater uncertainty demands more integrated information flows between partners.
Mechanisms to reduce information processing needs	Simplifying organizational tasks, reducing product complexity, and decentralizing decision-making to minimize the need for excessive information flow.	Standardizing processes across organizations (e.g., shared logistics protocols, common supplier evaluation criteria), reducing task variability through coordinated forecasting and demand planning, and outsourcing complex tasks to reduce interorganizational complexity.
Mechanisms to increase information processing capacity	Practices such as implementing advanced IT systems, fostering cross-functional teams, enhancing lateral communications, and formalizing data-sharing mechanisms to process more information effectively.	Collaborative IT systems (e.g., shared ERP and monitoring systems), joint problem-solving teams between organizations, and formalization of information exchange through real-time data sharing (e.g., electronic data interchange).

However, as exceptions increase and uncertainty grows, the hierarchy may become overloaded, which leads to the inability to effectively process information. Galbraith (1974) argues that in such situations organizational design strategies must be implemented to reduce information processing requirements posed for the hierarchy. For example, increasing slack resources, such as budget flexibility or safety stocks, ensure that unanticipated exceptions are less unlikely to take place and they have lesser impacts, thus reflecting reduced information processing demands. Self-containment refers to the implementation of output-based structures to simplify operations and reduce conflicts, where task-specific resource allocation is contained to autonomous groups, such as teams composed around product groups. Investment in information systems increases information processing capacity by improving the collection, storing, formalization, analysis and transfer of information across the organization. Creating lateral decision processes refers to transferring decision-making responsibility to lower tiers and enabling more informal collaboration across functions to solve problems without overloading the hierarchy. Such design strategy improves information processing capacity by enabling faster decision-making, reducing communication bottlenecks, and facilitating the flow of information across different organizational units. This decentralized approach allows for more timely responses to uncertainty and complex issues, as employees closest to the problem can collaborate directly, reducing the need for higher-level managerial intervention and enhancing the organization’s overall efficiency and adaptability.

Although the organizational information processing theory was originally adopted for the analysis of intra-organizational performance, subsequent research has further developed it in the inter-organizational context, particularly in the domain of supply chain management (Bensaou and Venkatraman, 1995; Premkumar *et al.*, 2005). This extension stems from the notion that organizations are open social systems that are susceptible to multiple sources of uncertainty in their operating environments (Tushman and Nadler, 1978). Such a notion is particularly useful, as it recognizes the uncertainty and its decision-making hindering effects emerging from inter-organizational relationships with supply chain partners and external stakeholders of the organization. The inclusion of inter-organizational information processing also allows the exploration of typical coordination problems and task interdependency both within and between organizations in a supply chain.

A vast body of empirical research has been made into the organizational information processing theory to explain organizational performance through the reduction of uncertainty. Acknowledging the wide range of context-specific factors, research consistently highlights that aligning information processing needs and capabilities leads to improved performance outcomes, particularly in settings where uncertainty plays a major role in generating risks or impedes decision-making. For example in the sustainability context, Dahlmann and Roehrich (2019) showed that different types of climate engagement strategies improve information processing and help manage emissions in supply chains. Similarly, research has revealed many types of mechanisms to reduce needs and increase capacity related to sustainability-related information processing, which contribute to beneficial sustainability outcomes in supply chains

(Busse *et al.*, 2017; Foerstl *et al.*, 2018). Several studies have also linked organizational information processing into better supply chain risk management, showing how information processing capacity reduces the amount of risks and the negative effects of disruptions in supply chains (Kauppi *et al.*, 2016; Fan *et al.*, 2017; El Baz and Ruel, 2021). Other exemplary studies have provided evidence of information processing being positively correlated with managerial performance (Daft *et al.*, 1987), capacity for better product innovation (Stock and Tatikonda, 2008), and procurement performance (Premkumar *et al.*, 2005).

2.7 Practice-based view and supply chain practice view

The practice-based view is built on the premise that organizational performance is driven by the execution of imitable and transferable practices. Practices, in this context, are defined as a set of activities that organizations can implement to achieve their goals (Bromiley and Rau, 2014). Practices are assumed not to be unique to specific firms, nor require rare resources or advanced capabilities. Instead, the theory suggests that performance variation between firms are partly explained due to how well these common practices are identified, adapted, and executed within the organization (Bromiley and Rau, 2016). As such, the practice-based view highlights a contrast with other organizational theories that focus on proprietary resources or firm-specific competitive advantages. Performance improvement is not proposed to stem from the possession of rare resources or exclusive capabilities, but from the organization’s ability to consistently and efficiently implement proven practices of which information is available to organizations. In other words, practices are expected to have weak or non-existent isolating mechanisms (Bromiley and Rau, 2014). These practices can range from routine operational procedures, such as quality control and standardized reporting, to more complex strategic processes, such as cross-departmental coordination and business process optimization.

The supply chain practice view is an extension of the practice-based view, developed to understand how interorganizational practices across supply chains influence performance. While the practice-based view focuses on how firms individually adopt and execute transferable practices to enhance performance, the supply chain practice view shifts the focus to collaborative practices that span multiple organizations within a supply chain (Carter et al., 2017). This perspective emphasizes that practices, rather than being confined to the boundaries of a single organization, often require joint efforts and coordination between firms to be effective. These practices are not limited to any particular firm but are shared across the supply chain network, contributing to both individual and collective performance outcomes. Similarly to the practice-based view, practices are expected to be imitable and transferable, meaning that other firms in the supply chain can adopt and replicate them. An overview of the practice-based view, supply chain practice view and their key assumptions are provided in Table 6.

Table 6: An overview of the practice-based view and supply chain practice view, based on Bromiley and Rau (2014, 2016) and Carter *et al*. (2017)

	Practice-based view	**Supply chain practice view**
Dependent variable	Intermediate and final performance outcomes at the intra-organizational level.	Firm-level performance and appropriated relational performance outcomes, spanning across supply chain partners.
Explanatory variables	Intra-organizational practices with weak or non-existent isolating mechanisms.	Inter-organizational practices with weak or non-existent isolating mechanisms.
Unit of analysis	Practice-performance link at the organizational level.	Practice-performance link on the supply chain dyad or network level.
Key assumptions	Not all firms adopt practices that could potentially enhance performance outcomes. Effects of practice use vary across firms, depending on contextual moderators.	Performance outcomes are driven by the joint implementation of interorganizational practices that require coordination and collaboration between partners.
Examples of practices	Internal operational practices related to purchasing processes, employee training, and workflow optimization.	Joint product development, supplier development programs and supply chain risk management.

A key concept within the supply chain practice view is relational performance, which refers to the benefits generated when two or more organizations collaborate within a supply chain. These outcomes, achieved through joint efforts, go beyond what any single firm could accomplish independently (Carter et al., 2017). Examples of practices driving relational performance include joint product development, supplier development programs, electronic data interchange, and collaborative planning and forecasting (Carter et al., 2017). These practices demand a higher level of coordination and involvement from supply chain partners compared to intraorganizational practices, which are confined within a single firm’s operations. Relational performance is related to the interdependence of firms in a supply chain, where the success of one is linked to the contributions of others. For instance, joint product development can promote innovations that benefit both a manufacturer and its suppliers, while supplier development programs enhance supplier quality and efficiency, improving overall supply chain reliability and reducing costs. These collaborative efforts can lead to improvements in lead times, cost reductions, and innovations, benefiting the entire supply chain.

So far, the practice-based theories have been adopted to explain the link between various practices and different performance outcomes in supply chains. For instance, Treacy *et al*. (2019) applied PBV to evaluate ISO 14001 adoption in UK and Irish manufacturing firms, finding that standardized environmental practices improved operational efficiency and employee productivity. However, they also noted diminishing returns for some operational indicators over time, highlighting the nuanced impacts of standardized practices. Studies show that biodiversity management practices in supply chains lead to positive environmental performance by address biodiversity loss and promoting environmental restoration (Salmi *et al.*, 2023). Collaborative practices, such as supply chain partnering has been found to contribute to improved operational and financial performance outcomes in supply chains (Kirchoff and Falasca, 2022). Schilling and Seuring (2024) found that multiple sustainable supply chain management practices that are driven by the digital transformation enhance both environmental and social performance outcomes.

3 Methodology

3.1 Research approach

Conducting research includes asserting beliefs and assumptions about the nature of reality and how generalizable knowledge can be obtained from it (Easterby-Smith *et al.*, 2015). These systems of beliefs which inherently affect the research process are collectively defined as research philosophy. Research philosophy includes the definition of (1) ontological and epistemological assumptions, (2) the mode of scientific reasoning with which theoretical contributions are intended to be made, (3) methodological choices aligned with the selected reasoning, and (4) devising research strategies in line with the methods, and (5) apply techniques and procedures to conduct data collection and analysis (Saunders *et al.*, 2016). The remainder of this section discusses these concepts and how they relate to the research conducted in this dissertation. Table 7 illustrates the different views on philosophical assumptions in business research.

3.1.1 Ontology and epistemology

Ontology addresses the nature of reality and what can be known about it. It shapes the assumptions researchers make about the world and influences how they approach their inquiries. In the context of business and management research, ontology provides the philosophical basis for exploring phenomena such as organizational behavior, market dynamics, or supply chain practices (Saunders *et al.*, 2016). Different ontological perspectives are associated with the debate about whether organizational phenomena exist independently of human actors (realism) or are constructed through social processes (relativism) (Easterby-Smith *et al.*, 2015). In other words, an ontological stance determines the degree to which the researcher believes that external phenomena are either objective or subjective. For example, research aligning under objectivism would assume research can be made only through observations that directly correspond to the studied phenomena. In contrast, subjectivism assumes that scientific laws or theories are constructed by the individuals embedded in the research.

Epistemology refers to the philosophical assumptions about what constitutes knowledge (Easterby-Smith *et al.*, 2015). In the context of research, epistemology guides the researcher in determining which methods and approaches are appropriate for exploring the research questions and generating meaningful insights (Crotty, 1998). Two dominant epistemological stances are frequently discussed in research: positivism and interpretivism (Saunders *et al.*, 2016). Positivism is rooted in the belief that knowledge is objective and can be observed, measured, and quantified. Researchers adopting this stance aim to uncover universal laws or patterns by testing hypotheses through rigorous empirical methods. This approach aligns with the broader aim of generalizability and replicability in quantitative research. Interpretivism, in contrast, emphasizes the subjective and socially constructed nature of knowledge. This stance prioritizes understanding over measurement and seeks to explore the meanings and experiences individuals ascribe to phenomena. Rather than relying on numerical metrics, interpretivist researchers would employ mostly qualitative methods, such as interviews or participant observation, to gather rich, contextual insights. This approach is particularly suited to exploring complex, multifaceted phenomena where social and relational dynamics play a crucial role.

Between the positivist and interpretivist paradigms lies critical realism, which is an increasingly influential philosophical stance in business research (Saunders *et al.*, 2016). Critical realism posits that while an objective reality exists, our understanding of it is always mediated by social structures and human interpretation (Bhaskar, 2008). While empirical observation is central to knowledge creation, critical realists emphasize that scientific consensus also plays a role in validating truths (Järvensivu and Törnroos, 2010). By integrating both objective and subjective dimensions, critical realism provides a balanced framework for examining complex systems and processes (Fleetwood, 2005). Moreover, critical realists assume that events are observed and experienced through human perception and mental processing, which requires reasoning backward (retroduction) to identify the underlying structures and mechanisms that caused them (Saunders *et al.*, 2016). This reasoning process emphasizes interpreting causal connections between events to uncover the hidden mechanisms that explain observable phenomena. This approach allows researchers to move beyond surface-level observations, focusing also on the deeper realities that may shape events and outcomes. This dissertation adopts critical realism as its philosophical foundation to investigate complex, multi-layered phenomena within the supply chain context.

Table 7: Ontology, epistemology, and methodology (based on: Järvensivu and Törnroos, 2010; Easterby-Smith *et al.*, 2015; Saunders *et al.*, 2016)

	Positivism	**Critical realism**	**Interpretivism**
Ontology *Nature of reality*	Reality is objective, independent of human perception, and can be observed and measured	Reality exists independently but is stratified into observable events, mechanisms, and structures	Reality is socially constructed and influenced by individual and group perceptions and interactions
Epistemology *What constitutes knowledge*	Knowledge is derived from objective observation and measurable facts	Knowledge reflects the interplay of observable events and the underlying mechanisms causing them	Knowledge is co-created through interaction and interpretation of meaning between researcher and participants
Purpose of research	To test hypotheses, uncover universal laws, and predict phenomena	To explain causal relationships by identifying and understanding their potential mechanisms between observable events and patterns in their change.	To explore and interpret the meanings individuals or groups assign to experiences and phenomena.
Methodology	Predominantly quantitative, such as surveys, experiments, or statistical modeling	Quantitative and qualitative	Employing predominantly qualitative methods to uncover rich insights
Role of the researcher	Independent from what is being observed	Mixed—acknowledges objective realities but recognizes the influence of context and interpretation	Part of what is being observed
Role of theory	Theory is used to generate hypotheses and is verified or falsified through empirical data collection	Theory explains observed patterns by identifying and conceptualizing the underlying structures or mechanisms that cause phenomena. Theory also integrates empirical findings with context to refine understanding	Theory emerges during or after the research process, grounded in the lived experiences of participants

3.1.2 **Scientific reasoning**

A commonly accepted notion on scientific reasoning in organizational research is that theories are created, tested and elaborated through three different reasoning mechanisms:

inductive, deductive, and abductive reasoning (Mantere and Ketokivi, 2013). Understanding the ways of reasoning that the researcher adopts is considered important because it shapes the formulation of research questions, guides the methodological choices, influences the interpretation of findings, and ensures that the research process is coherent and aligned with the study's objectives (Saunders *et al.*, 2016). Reasoning can be seen as the bridge between specific empirical data that the researchers have, and the theoretical generalizations they attempt to make of such data (Ketokivi and Mantere, 2021). Moreover, the logical processes associated with reasoning culminate in the researchers ability to make compelling arguments that increase the validity of theoretical claims made on the studied phenomena through the minimization of potential bias or the addressing of inherent limitations in the data or the applied reasoning methods themselves (Locke and Golden-Biddle, 1997; Toulmin, 2003; Ketokivi and Mantere, 2021). A summary of the types of scientific reasoning is illustrated in Table 8.

Table 8: The general forms of scientific reasoning in organizational studies (Mantere and Ketokivi, 2013; Ketokivi and Choi, 2014; Saunders *et al.*, 2016; Ketokivi *et al.*, 2017; Behfar and Okhuysen, 2018)

Type of reasoning	**Definition**	**Associated methodological/logical processes**
Inductive reasoning	Generalization from observations is based on probabilistic claims made through observed (historical) patterns in empirical data; conclusions are not guaranteed true.	Sampling, pattern recognition, and probabilistic logic
Deductive reasoning	Particular conclusions made from observations, which are based on determining general premises; such conclusions are necessarily true, given the premises are valid.	Logical deduction, hypothesis testing, and empirical validation
Abductive reasoning	Iteratively combining empirical findings with theoretical understanding to a plausible explanation for observed phenomena. It is applied often in conditions of incomplete data. Abductive reasoning cannot result into a generalization.	Hypothesis generation, iterative reasoning, and plausibility-based logic

First, inductive reasoning relies on the observation of patterns within empirical data to make generalizations. In other words, inductive reasoning follows from particular observations into generalizations (Ketokivi and Mantere, 2010). Research based on inductive reasoning uses techniques such as sampling, pattern recognition, and probabilistic logic to infer broader trends from specific instances. While the conclusions derived are not guaranteed, they offer a strong pragmatic foundation for understanding recurring phenomena based on historical data (Saunders *et al.*, 2016). When contrasted with deduction, inductive reasoning amplifies knowledge, because it adds information merely beyond what can be analytically stated on the basis of premises (Ketokivi and Mantere, 2010). Inductive reasoning approach is commonly employed when studying large datasets or diverse organizational contexts to identify generalizable insights about particular behaviours or outcomes.

Second, deductive reasoning proceeds by deriving specific conclusions from general premises, meaning that these conclusions must analytically follow from the premises (Mantere and Ketokivi, 2013). In research, deductive reasoning is thought to emphasize logical deduction and hypothesis testing, where empirical validation is used to confirm or refute pre-existing propositions. Typically, it is claimed that this approach is being employed when evaluating the validity of established theories or principles, providing structured and conclusive results based on strict logical consistency. Deductive reasoning is applied when premises are agreed and conclusions naturally follow from it; as such, validity of claims made through deductive reasoning rely on the validity of premises (Behfar and Okhuysen, 2018).

Third, abductive reasoning combines empirical observations with existing theoretical frameworks or subjective sensemaking to construct plausible explanations for observed phenomena. Abductive reasoning may begin with recognizing surprising conclusions, whose preceding causes require retrospective consideration and hypothesizing (Ketokivi and Mantere, 2010). Thus, sometimes abduction is referred to as “an inference to the best explanation”. However, this notion has been heavily debated in the reasoning literature, as what constitutes as “best” is often subjective and requires further layers of reasoning (Niiniluoto, 2018). Interestingly, it follows that the abductive reasoning method is at the centre of discovering new ideas in the form of alternative hypotheses or plausible local explanations for observed phenomena (Behfar and Okhuysen, 2018). It is particularly effective under conditions of incomplete or ambiguous data, as it focuses on iterative refinement to reconcile gaps between what is observed and what is theoretically understood.

This dissertation applies a combination of inductive and abductive reasoning in its associated research publications. Inductive reasoning is predominantly evident in Publication I, where statistical inference was used to make probabilistic claims. Publications I-IV are also characterized by an abductive reasoning approach, which entails formulating hypotheses (Publication I), analyzing and structuring qualitative data to propose plausible explanations for the studied phenomena (Publications II-IV), and undertaking sensemaking to connect theoretical understanding with the collected primary data by means of theory elaboration (Publication II and III). Additionally, the abductive reasoning approach was used to generate propositions (Publication II).

3.2 Research methods, data collection, and data analysis

This dissertation adopted both quantitative and qualitative approaches to study the research questions. This section illustrates the data collection and methodological choices related to Publications I, II, III and IV.

3.2.1 Publication I (Quantitative research)

Publication I employs a quantitative research methodology to explore the impact of procurement digitalization on supply chain resilience. The study was designed to assess relationships between procurement digitalization, supply chain risk management (SCRM), and supply chain resilience (SCRES) using survey data collected from firms in Finland. The specific focus was on the role of digital technologies use in improving information processing capacities and reducing uncertainty within the supply chain.

Data collection and sampling

Data were gathered through a cross-sectional survey sent to procurement professionals in 383 companies across the Finnish manufacturing and retail sectors, targeting firms with at least 100 employees and an annual turnover of €50 million. The survey received 147 valid responses, yielding a response rate of 38.4%. The respondents were distributed across various organizational roles, including top management (21.8%), middle management (46.3%), operational roles (11.6%), and expert positions (19.7%). The survey was designed based on established constructs from the literature, including data analytics (Brinch *et al.*, 2018), information sharing (Fan *et al.*, 2017), procurement process digitalization (van Weele, 2014), supply chain risk management (Hallikas and Lintukangas, 2016), and supply chain resilience (Ambulkar *et al.*, 2015). Each construct was measured using a multi-item Likert scale. For example, data analytics measured the level of firms' utilization of data-driven tools for decision-making, while information sharing focused on the frequency and quality of information exchanges between supply chain partners.

Data analysis

The collected data were analyzed using Partial Least Squares (PLS) path modeling, a robust statistical technique suitable for small-to-medium sample sizes and models with both formative and reflective constructs. PLS was selected due to its ability to handle complex models with multiple relationships between latent variables and because it provides reliable estimates in situations where data normality cannot be assumed (Hair *et al.*, 2017). The analysis was conducted using SmartPLS 3.0 software, following a two-step process. First, the measurement model assessment involved confirming construct reliability and validity by using composite reliability (CR) and average variance extracted (AVE) values, both of which exceeded recommended thresholds (CR > 0.7; AVE > 0.5) (Fornell and Larcker, 1981; Gefen and Straub, 2005; Kline, 2011; Henseler *et al.*, 2014). Second, the structural model was assessed by testing path coefficients for statistical significance using bootstrapping with 5,000 resamples. The model's explanatory power was evaluated using R-squared (R^2) values for the dependent variables, with SC resilience (SCRES) achieving an R^2 of 0.318, indicating moderate explanatory power. Key relationships tested in the model included the impact of data analytics and procurement digitalization on supply chain risk management and resilience. Significant paths were identified, confirming that supply chain risk management mediates the positive effects of procurement digitalization on supply chain resilience. To ensure the reliability of the results, the study applied several robustness checks. Collinearity was assessed using the Variance Inflation Factor (VIF), with all values falling below the critical threshold of 5. The Heterotrait-Monotrait (HTMT) ratio was used to verify discriminant validity, ensuring that each construct was sufficiently distinct from the others (Hair *et al.*, 2019).

3.2.2 **Publication II (Qualitative research)**

Publication II employs a qualitative research methodology to investigate the role of risk management practices in IT service procurement, using a single-case study approach. The study explores the relationship between risk management practices and service performance in the context of IT procurement in the financial services industry.

Data collection and sampling

The data collection was conducted through semi-structured interviews and analysis of secondary data, based on an in-depth single case study. The primary data was collected from 16 informants during 14 interviews with representatives from a focal financial services company and its three major IT service providers. A purposive sampling approach was adopted (Patton, 2002): interviewees were selected based on their expertise and direct involvement in IT service procurement and risk management. The focal company plays a key role in the financial services industry, relying heavily on outsourced IT services, which made it an ideal case for studying risk management during procurement processes. The interviewees from the focal company included managers responsible for procurement, IT service management, information security, and risk management. Interviews were conducted with 11 participants from the focal company and three participants from the service providers, ensuring diverse perspectives for investigating the research problem. The interviewees were asked open-ended questions designed to explore key risk factors, risk management practices during procurement processes, and the role of collaborative risk management. In addition to the interviews, secondary data, such as the focal company's publicly available reports, were also analyzed to support the qualitative analysis and ensure triangulation of findings.

Data analysis

The qualitative data were analyzed using content analysis, following the Miles and Huberman (1994) framework, which includes data reduction, data display, and conclusion drawing. The interviews were transcribed, and the data were coded using NVivo to identify patterns, themes, and relationships. The analysis focused on understanding the stages of the procurement process and how risk management practices were implemented during each stage. Particular attention was paid to the ex ante, contracting, and ex post contract phases of the service procurement process. An inductive coding approach was used to generate first-order codes related to risk factors and management practices. In line with the theory elaboration approach (Ketokivi and Choi, 2014; Fisher and Aguinis, 2017), the identified practices and related routines were later linked to established constructs from the literature related to the procurement and risk management processes. The analysis identified several critical routines for managing risks, such as risk identification, assessment, mitigation, and monitoring. To ensure validity, the coding categories were iteratively assessed by the authors and verified through a panel review with key participants from the focal company during a follow-up workshop.

3.2.3 Publication III (Qualitative research)

Publication III adopts a qualitative research methodology to investigate how different sources of uncertainty affect information processing related to Scope 3 emissions within the steel supply chain. The study focuses on understanding how organizations may manage uncertainties in measuring and reporting greenhouse gas emissions across their SCs, particularly in the steel industry. The research contributes to the ongoing literature on the role of organizational information processing in sustainable SC management.

Data collection and sampling

Data for Publication III were collected through semi-structured interviews with 16 senior managers and experts from 12 European organizations across the steel supply chain. These organizations represent various segments of the supply chain, including upstream suppliers, downstream manufacturers, logistics providers, and intermediary service providers specializing in environmental sustainability consulting and business analytics. The semi-structured interview approach allowed the researchers to explore context-specific challenges associated with Scope 3 emissions measurement while maintaining consistency across interviews (Creswell, 2013).

A purposive and criterion-based sampling strategy was employed (Patton, 2002) to ensure that participants were selected based on their direct involvement in the steel industry and their expertise in GHG emissions measurement and reporting. The sampling approach was designed to capture diverse perspectives on the challenges of Scope 3 emissions reporting from different stages of the supply chain. The sample included key actors from the upstream (raw material production), downstream (manufacturing, logistics, and wholesale), and intermediary sectors, ensuring comprehensive coverage. This intentional selection of participants helped provide meaningful insights and supported data saturation (Guest *et al.*, 2006).

Interviews were conducted via video calls, allowing for participation from various locations, and ensuring consistency in data collection. Each interview was transcribed verbatim to provide an accurate record of the discussions. To ensure reliability, at least two researchers were present during each interview, which facilitated the validation of data and reduced potential interviewer bias. The primary selection criteria for participants included active involvement in Scope 3 emissions reporting or sourcing and the use of steel or steel-based products. This ensured that the selected organizations and individuals were relevant to the research objectives, providing context-specific insights into the steel industry's unique challenges related to GHG emissions.

Data analysis

The qualitative coding process was based on a thematic analysis (Saldaña, 2013). The transcribed interview data were coded using NVivo to identify recurring patterns, themes, and relationships concerning sources of uncertainty and their impact on information processing. The analysis focused first on how uncertainties related to environmental factors, tasks, sourcing, supply chain structure, technology, and partnerships affected the measurement and reporting of Scope 3 emissions.

An inductive coding approach (Gioia *et al.*, 2013) was adopted to generate first-order codes, which represented specific challenges, uncertainties and information processing mechanisms encountered by the interviewed organizations and their supply chain. These were later grouped into broader categories aligned with the sources of uncertainty identified in the literature. Following the theory elaboration approach (Ketokivi and Choi, 2014; Fisher and Aguinis, 2017), the identified uncertainties were further analyzed to understand their influence on information processing within SCs. Similar coding of the primary data was made for information processing mechanisms, which were linked to the identified sources of uncertainty.

The analysis process involved multiple iterations, where initial coding was reviewed and refined by the research team to ensure robustness. Coding categories were revisited to enhance reliability, and emergent themes were discussed with key participants from the study during follow-up interviews, ensuring the validity of findings. This iterative process enabled the researchers to draw connections between uncertainty sources and information processing challenges, contributing to the understanding of how organizations manage GHG emissions-related uncertainties in complex SCs.

3.2.4 **Publication IV (Qualitative research)**

Publication IV employs a qualitative research methodology to investigate the drivers, challenges and practices related to sustainability in IT service procurement context, using a single-case study approach. The study proposes a theoretical framework for ensuring sustainability in ICT service supply chains.

Data collection and sampling

Publication IV employs a qualitative research methodology using an in-depth single-case study design to explore the challenges, drivers, and practices for ensuring sustainability in ICT service procurement within the financial services sector in Finland. The case study approach was deemed appropriate due to its suitability for investigating underexplored phenomena and answering "how" and "why" questions (Yin, 2009). The focal firm, referred to as the lead firm, operates as a major player in the financial services industry, with a substantial reliance on outsourced ICT services, making it an ideal setting for examining sustainability in ICT service supply chains.

The data collection involved 14 semi-structured interviews with 16 informants. Participants included 11 representatives from the lead firm and three representatives from its strategically critical ICT service suppliers. Informants were selected through purposive and snowball sampling techniques based on their expertise in procurement, sustainability, ICT service management, risk management, and data protection. This ensured diverse perspectives on the research topic. The interview questions were designed to elicit insights into sustainability challenges, drivers, and practices in the ICT service context. The interviews were recorded and transcribed verbatim. To complement the interview data, secondary data sources, such as publicly available reports from the lead firm, were also analyzed to triangulate findings.

Data coding

The analysis of the qualitative data followed the structured method outlined by Gioia *et al*. (2013) enabling the study to move systematically from empirical observations to theoretical insights. First, the interview transcripts were reviewed to generate first-order, informant-centric codes that reflected the language and perspectives of the participants. These codes were subsequently grouped into second-order researcher-centric themes, which aligned with the study's conceptual focus on sustainability challenges, drivers, and practices in ICT service procurement. NVivo 12 was used to facilitate the coding process and ensure accuracy in identifying patterns and relationships within the data. The identified themes were synthesized into a cohesive theoretical framework for sustainable ICT service supply chains. To ensure the validity and reliability of the analysis, coding categories and interpretations were iteratively reviewed by the research team and further validated during a workshop with representatives from the lead firm.

3.2.5 Summary of research methodology

The dissertation adopts both quantitative and qualitative research approaches across four publications. Publication I uses a quantitative approach to examine how procurement digitalization influences supply chain resilience, utilizing survey data from 147 respondents and analyzed through Partial Least Squares (PLS) modeling. Publication II employs a qualitative, single-case study approach, focusing on risk management practices in IT service procurement, based on 14 semi-structured interviews, analyzed through content analysis using NVivo. Publication III investigates sources of uncertainty and their effects on information processing regarding Scope 3 emissions in the steel industry, using qualitative data from 16 interviews, analyzed with the organizational information processing theory framework. Publication IV investigates sustainability in the context of ICT service procurement, using qualitative data from 16 interviews to analyze drivers, challenges and practices. The summary of the dissertation’s research methodology is illustrated in Table 9.

Table 9: Summary of the dissertation's research methodology.

	Publication I	Publication II	Publication III	Publication IV
Research objectives	Investigates how procurement digitalization affects supply chain resilience.	Investigates the role of risk management practices in IT service procurement.	Investigates the sources uncertainty and their effects on information processing related to Scope 3 emissions.	Investigates how sustainability is ensured in IT service procurement.
Research approach	Quantitative, based on cross-sectional survey data.	Qualitative, single-case study approach with semi-structured interviews	Qualitative study, multiple informant organizations within the steel industry, with semi-structured interviews	Qualitative, single-case study approach with semi-structured interviews
Theoretical lens	Organizational information processing theory	Practice-based view and supply chain practice view	Organizational information processing theory	-
Data collection	Survey sent to 383 companies in the Finnish manufacturing and retail sectors. 147 valid responses received. Multi-item Likert scales based on constructs established in the literature	14 semi-structured interviews conducted with 16 informants (11 from focal company, 5 from IT service providers). Secondary data (e.g., reports)	16 semi-structured interviews conducted with senior managers and experts from 12 European organizations in the steel SC	14 semi-structured interviews conducted with 16 informants (11 from focal company, 5 from IT service providers)
Sampling	Purposeful sampling	Purposeful sampling	Purposeful sampling	Purposeful sampling
Data analysis	Partial Least Squares (PLS) path modeling using SmartPLS 3.0	Qualitative content analysis, following the Miles and Huberman (1994) framework	Qualitative content analysis. Abductive thematic coding following the principles of Saladaña (2013) and Fisher and Aguinis (2017)	Qualitative content analysis, following the principles Gioia et al. (2013) framework
Key constructs	Data analytics, information sharing, procurement process digitalization, supply chain risk management, supply chain resilience	A typology of relevant risk factors Risk identification, risk assessment, mitigation, and monitoring routines	Environmental, task, source, supply chain, technology and partnership uncertainty	Drivers, challenges and practices related to sustainability in ICT service procurement

3.2.6 Quality criteria

Ensuring research quality across the dissertation is critical to establishing the credibility of the findings. This section addresses the reliability, validity, and generalizability of the methods used in both the quantitative and qualitative studies. Specific considerations for reliability and validity are presented in Publications I-IV.

Reliability

Reliability is defined as the consistency and repeatability of the research outcomes, particularly concerning the data collection and analysis processes (Saunders *et al.*, 2016). In the quantitative study (Publication I), the survey instrument was designed using established constructs from the literature (e.g., data analytics, information sharing, supply chain risk management), which enhances the reliability of the measures. Moreover, the use of Partial Least Squares (PLS) path modeling requires robust internal consistency for the measurement model, which was confirmed through composite reliability (CR > 0.7) for all constructs (Hair *et al.*, 2019). The application of bootstrapping with 5,000 resamples further supports the reliability of the results by providing stable estimates for the path coefficients.

In the qualitative studies (Publications II, III and IV), reliability was ensured through the adoption of a semi-structured interview protocol, which provided a consistent interview guide across all participants. This approach reduces variability in the data collection process while allowing for flexibility in exploring context-specific insights (Yin, 2014). Additionally, the use of NVivo software for coding and analyzing qualitative data ensures consistency in the coding process. An audit trail of coding decisions and iterative reviews of the coding categories by multiple researchers added to the reliability of the findings (Miles and Huberman, 1994; Miles *et al.*, 2014). Triangulation through multiple data sources further contributed to the reliability by corroborating key insights across different perspectives and datasets.

Internal and external validity

Validity encompasses the accuracy and truthfulness of the research findings, including construct validity, internal validity, and external validity (Creswell, 2014). In Publication I, construct validity was strengthened by using well-established scales from the literature, ensuring that the survey items accurately captured the constructs of interest (Fornell and Larcker, 1981). The measurement model was further validated through Average Variance Extracted (AVE > 0.5), and discriminant validity was confirmed using the Heterotrait-Monotrait (HTMT) ratio (Hair *et al.*, 2019). Internal validity was addressed by testing for collinearity (VIF values below 5), ensuring that multicollinearity did not bias the relationships between variables.

In the qualitative studies (Publication II, III and IV), validity was enhanced through triangulation by using multiple data sources, such as protocol-based interviews and secondary data (Denzin and Lincoln, 2011). This approach helps cross-verify the findings, ensuring a more robust understanding of the phenomena under investigation. Publication II and IV specifically utilized a panel review with key informants from the focal company to confirm the accuracy of the interview data and interpretations (Patton, 2002). Similarly, Publication III involved multiple informant organizations across the steel industry, allowing for a diverse set of perspectives from a purposeful sample, which improves the credibility of the findings (Fisher & Aguinis, 2017). To further ensure validity, the studies employed data saturation principles by continuing data collection until little to no new themes emerged, thereby increasing the comprehensiveness of the findings (Guest *et al.*, 2006). Additionally, consistency in coding was ensured through researcher triangulation, where multiple researchers reviewed and refined the coding structure to reduce subjective bias and improve inter-coder reliability (Patton, 2002).

External validity refers to the generalizability a study's findings in relation to a specific domain of research or literature (Voss *et al.*, 2002). The assessment of external validity of the findings varies between the quantitative and qualitative studies. Publication I used a cross-sectional survey targeting large firms in Finland, specifically focusing on manufacturing and retail sectors. Although the survey sample is geographically limited, the broad industry representation provides a reasonable basis for generalizing the findings to similar firms in other regions (Bryman and Bell, 2015). Additionally, the focus on procurement digitalization and supply chain resilience ensures relevance to global supply chain management practices, especially in contexts where digital technologies are being adopted.

The qualitative approaches in Publications II, III and IV were designed to offer theoretical generalizability rather than statistical generalizability (Yin, 2014). Publications II and III used theory elaboration approach to contribute to theoretical discussion on the organizational information processing theory (Galbraith, 1974), practice-based view and supply chain practice view (Bromiley and Rau, 2014; Carter *et al.*, 2017). Publication IV used a qualitative coding approach independent from theoretical assumptions (Gioia *et al.*, 2013) to conceptualize how sustainability is ensured in the ICT procurement context. The use of purposeful sampling in these studies ensures that the informants selected could provide in-depth insights into risk management practices and information processing in IT procurement (Publication II), sustainability-related issues in ICT procurement (IV) and information processing regarding Scope 3 emissions (Publication III). These findings are valuable for theory development and can be applied to similar contexts, especially where organizations face complex procurement environments or information processing challenges. However, the unique characteristics of the focal companies and industries studied limit the generalizability of the results to other industries or regions without caution.

Ethical considerations

To maintain ethical standards, the research adhered to confidentiality and informed consent protocols. All participants were briefed on the research objectives, and their anonymity was ensured during data collection and analysis. Ethical approval for the studies was obtained in line with institutional guidelines of the Finnish National Board on Research Integrity (TENK).

4 Results

This section provides a summary of the four publications that are a part of this dissertation.

4.1 Publication I: The impact of procurement digitalization on supply chain resilience: empirical evidence from Finland

Background and research objectives

The digital transformation of supply chains has become increasingly important, particularly in enhancing their resilience amidst global disruptions. Procurement plays a critical role in this transformation, as organizations adopt digital technologies to streamline processes, improve data analytics, and enhance information sharing with supply chain partners (Handfield *et al.*, 2019; Srai and Lorentz, 2019; Lorentz *et al.*, 2021). Recent studies suggest that digitalization can be a key driver of supply chain risk management, helping firms mitigate risks and improve resilience in supply chains. Despite the growing interest in supply chain digitalization, limited empirical research has specifically examined the impact of procurement digitalization on supply chain resilience. The objective of Publication I was to address this gap by investigating how procurement digitalization, through data analytics, information sharing, and digital maturity, influences supply chain risk management and resilience. The conceptual model which was investigated in Publication I is illustrated in Figure 3.

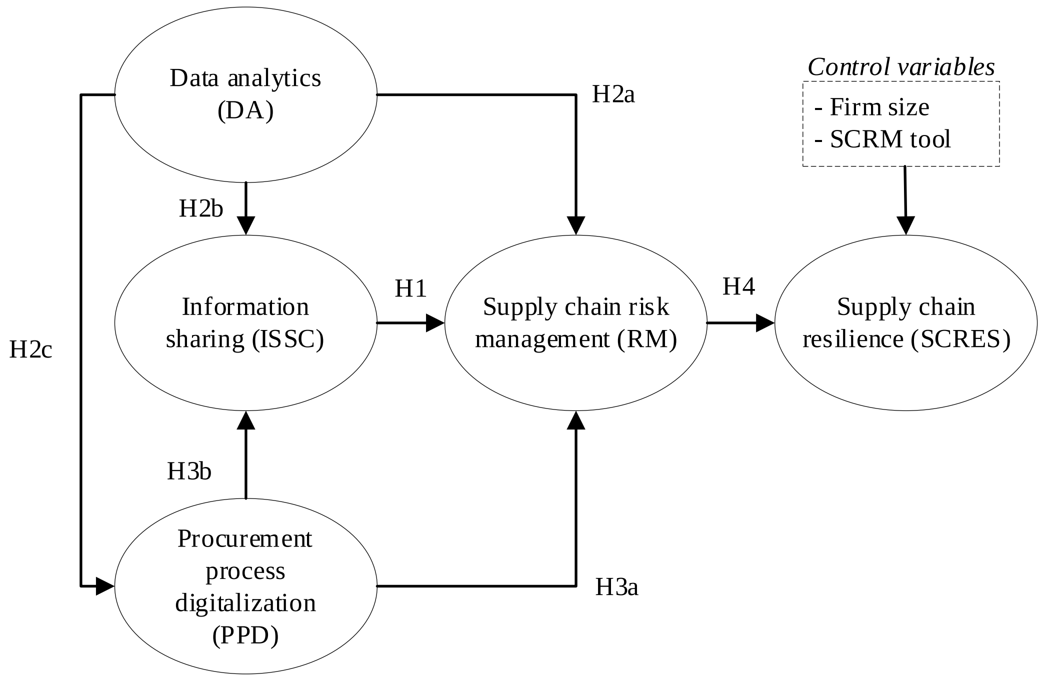


Figure 3: The conceptual model in Publication I

Main results and contributions

The study presented an empirically validated model demonstrating the positive impact of procurement digitalization on supply chain resilience (Table 10). The results showed that procurement digitalization, through data analytics and digital process maturity, enhances information sharing among supply chain partners, which positively influences supply chain risk management. Furthermore, the study found that supply chain risk management has a significant effect on supply chain resilience. This research integrated organizational information processing theory to illustrate how digitalization reduces uncertainty and improves information flow, thereby strengthening risk management and, ultimately, enhancing resilience across the supply chain.

The study confirmed that information sharing plays a pivotal role in improving risk management. The path from information sharing to risk management ($\beta = 0.302$, $p < 0.05$) was statistically significant, affirming that firms with better communication and transparency between supply chain partners are more adept at managing risks. This showed the critical importance of seamless information exchange, especially in mitigating uncertainties. The relationship between data analytics and risk management was found to be non-significant ($\beta = 0.053$, $p > 0.05$). This result suggested that while data analytics is essential, its influence on risk management is not direct. Instead, data analytics contributes indirectly to risk management through information sharing, as the study demonstrated a strong, positive relationship between data analytics and information sharing ($\beta = 0.480$, $p < 0.001$). Firms that effectively use data-driven tools to gather, process, and disseminate information can achieve higher levels of transparency and collaboration with their supply chain partners, thereby indirectly enhancing their risk management capabilities. Another important finding was the positive relationship between data analytics and procurement process digitalization ($\beta = 0.404$, $p < 0.001$), illustrating that firms leveraging data analytics are more likely to advance in their digital process maturity. However, the direct relationship between procurement process digitalization and risk management ($\beta = 0.040$, $p > 0.05$) was found to be insignificant, indicating that while digital processes enhance procurement efficiency, they may not independently impact risk management. Instead, the data showed that procurement process digitalization significantly enhances information sharing ($\beta = 0.247$, $p < 0.01$), suggesting that digitalized procurement practices lead to more effective communication and transparency, which, in turn, can help mitigate risks. The relationship between supply chain risk management and supply chain resilience was particularly noteworthy. The study found a highly significant positive impact of risk management on resilience ($\beta = 0.435$, $p < 0.001$), reinforcing the argument that effective risk management practices are crucial for maintaining and improving supply chain resilience, especially in dynamic and unpredictable environments. Firms that excel in identifying, assessing, and mitigating risks are better positioned to absorb and recover from disruptions, thereby ensuring more stable and resilient operations. Additional post-hoc analyses further supported the study's conclusions. For instance, the total effect of data analytics on supply chain resilience (β

= 0.338, $p < 0.001$) was significant, implying that data analytics, when integrated with information sharing and risk management, significantly contributes to the resilience of the supply chain. Similarly, procurement process digitalization had a significant total effect on supply chain resilience ($\beta = 0.234$, $p < 0.05$), emphasizing that it plays a key role in building resilient supply chains, even though its effect is primarily mediated through information sharing.

Table 10: Results of the structural model in Publication I

Hypothesis	**Path**	**β**	**T-statistics**	**p-values**
H1	ISSC → RM	0.302	2.302	p < 0.05
H2a	DA → RM	0.053	0.481	Not significant
H2b	DA → ISSC	0.480	7.140	p < 0.001
H2c	DA → PPD	0.404	5.381	p < 0.001
H3a	PPD → RM	0.040	0.301	Not significant
H3b	PPD → ISSC	0.247	3.224	p < 0.01
H4	RM → SCRES	0.435	5.396	p < 0.001
Post hoc tests				
Total effect	DA → SCRES	0.338	4.311	p < 0.001
	ISSC → SCRES	0.132	1.934	Not significant
	PPD → SCRES	0.234	2.100	p < 0.05

The results from Publication I confirmed that procurement digitalization, particularly through the application of data analytics and digital processes, enhances information processing capacities across supply chains. By improving information sharing and risk management, digitalization significantly strengthens supply chain resilience. These findings provide strong empirical support for organizational information processing theory, demonstrating that digital technologies help firms mitigate supply chain risks by reducing uncertainty and improving the efficiency and effectiveness of decision-making processes. Specifically, the study provided empirical evidence that procurement digitalization improves resilience by enhancing information sharing systems, which act as critical enablers of supply chain risk management. In turn, supply chain risk management significantly improved supply chain resilience, aligning with the findings of Fan *et al*. (2017), Jüttner and Maklan (2011), and El Baz and Ruel (2021), who highlighted the similar connections between risk management and resilience. Moreover, the study extended theory by illustrating how procurement digitalization reduces uncertainty, largely mediated by information-sharing mechanisms that facilitate the real-time processing and dissemination of procurement-related data. This confirmed that digital technologies significantly enhanced firms' abilities to process information, thereby mitigating risks and improving resilience. These findings are consistent with previous research suggesting that digital maturity increased a firm's capacity to handle disruptions

(Ivanov *et al.*, 2019; Fischer-Preßler *et al.*, 2020). Additionally, the research contributed to the emerging discussion on procurement digitalization by analyzing how data analytics and digital process maturity were linked to risk management. While data analytics did not directly impact risk management, its role in improving information sharing was significant, reinforcing the need to optimize information processing capacities across the supply chain to manage risks effectively (Fan *et al*., 2017). Finally, Publication I addressed a gap in the literature regarding the specific role of procurement functions in supply chain resilience. Previous studies had primarily focused on supply chain-wide digitalization, leaving the procurement-specific impact underexplored (Srai and Lorentz, 2019; Van Hoek, 2020). By focusing on procurement-specific digitalization practices, this study added depth to the understanding of how firms could leverage procurement to enhance resilience.

4.2 Publication II: The role of risk management practices in IT service procurement: A case study from the financial services industry

Background and research objectives

Research has shown that the service transactions may be complex due to the nature of service characteristics being intangible and the value of services often involving the subjective perceptions of customers during interactions related to service exchanges (Vargo and Lusch, 2008). In a procurement context, such characteristics may lead to unique risks from the buyer organization's perspective (Ellram *et al.*, 2008; Lacity *et al.*, 2016). Prior research has indirectly explored the importance of risk management in service procurement, but there has been limited focus on explicitly understanding how risk management routines are applied and how they benefit the performance of purchased services (Wynstra *et al.*, 2015). In Publication II, the objective was to investigate the role of risk management practices during the procurement, specifically in the IT services context, by examining how service-related risks can be identified, assessed, mitigated, and monitored throughout the procurement process. In industries such as the financial services, IT service procurement has been increasingly reliant on risk management practices crucial for ensuring operational continuity and protection against disruptions (Adeleye *et al.*, 2004), yet research has been nascent. To fill this gap, Publication II sought to examine how risk management routines are operationalized during the IT service procurement process, particularly focusing on how these practices influence service performance and mitigate service-related risks within and across organizational boundaries. The research framework guiding the investigation for Publication II is shown in Figure 4. The theoretical lens for this study was the practice-based view and supply chain practice view, which were integrated in the qualitative analysis to better understand organizational routines related to risk management during the IT service procurement process, and their potential benefits to the performance of purchased IT services. This case study was conducted within a large financial services company and its three key IT service providers, using a combination of semi-structured interviews and secondary data. The study was guided by the following research questions:

1. *What are the major risk factors related to the procurement of IT services?*
2. *What practices are used to manage risks during the service procurement process?*

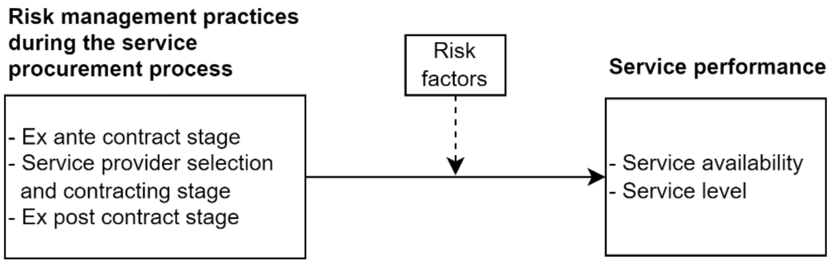


Figure 4: Research framework for Publication II

Main results and contributions

The findings of Publication II provided insights into how risk management practices are operationalized within IT service procurement. The study revealed that risk management activities are embedded at various stages of the procurement process for services, including the ex-ante phase, where risks are identified and assessed before contractual agreements are made, and the post-contractual phase, where risks are mitigated and monitored during service delivery. This study also identified a typology of risk factors that the focal company encounters during IT service procurement and service management processes (Table 11). The findings regarding risk management practices are illustrated in Figure 5.

Table 11: Findings regarding the risks factors in IT service procurement in Publication II

Context	**Risk factors**
Service provider	Insufficient operational capabilities Financial instability Regional instability Concentrated spend and lock-in effects Adverse reputation Lack of sustainability or business ethics
Internal processes and governance related to risk management	Lack of internal visibility and siloed information Ineffective human resource management Ambiguities in process ownership and task allocation between units Difference in risk perceptions Regulatory non-compliance Inconsistencies in risk information collection activities Lack of management support
Technology and service provision	Information security vulnerabilities Potential of user errors Insufficient duty separation Interdependency of service assets Low intensity of collaboration in risk management activities

In the ex-ante phase, it was found risk management supports procurement outcomes for the focal company primarily through the identification and assessment of risks. Identification includes evaluating risks related for example, to the service provider, service integration processes, and service supply chain risks. The focal company also used formal risk assessment tools and frameworks to evaluate the likelihood and potential impact of identified risks. This systematic approach to risk assessment ensured that risks were categorized and prioritized, allowing the firm to focus on mitigating the most critical risks.

The study also highlighted the importance of contractual safeguards in mitigating risks during the contracting phase. The findings showed that service-level agreements, penalty clauses, and performance metrics were commonly used to enforce compliance and protect the focal company from potential failures in service delivery. These contractual mechanisms were particularly effective in managing legal and compliance risks, which were a major concern, given the regulatory landscape in which the focal firm operated in. By ensuring that clear performance expectations were established, the firm could mitigate the risk of non-compliance or service underperformance. Moreover, we found that the implementation of risk governance and contingency planning emerged as a critical risk management routine before service development and delivery processes were in place.

In the post-contractual phase, the study revealed that continuous risk monitoring and supplier performance evaluation were integral to the firm's risk management strategy. The financial services firm conducted regular performance reviews to assess the supplier's performance against the agreed-upon terms. Monitoring mechanisms such as regular review meetings and audits were also essential for tracking ongoing risks and ensuring that any emerging issues were addressed promptly. These monitoring practices contributed to risk mitigation, particularly in the context of supplier-related risks and operational risks that arose during the course of service delivery. Importantly, the study found that in the ex-post phase, the focal company relied heavily on collaborative risk management with service providers, enabling a more comprehensive understanding of potential risks especially during service delivery. This collaborative approach was particularly effective for identifying technological and operational risks, which required joint expertise between the buyer and the supplier. Examples risk management activities included collaborative IT service management, incident resolution processes, establishing protocols for communication and proactively testing and improving contingency plans for service disruption recovery.

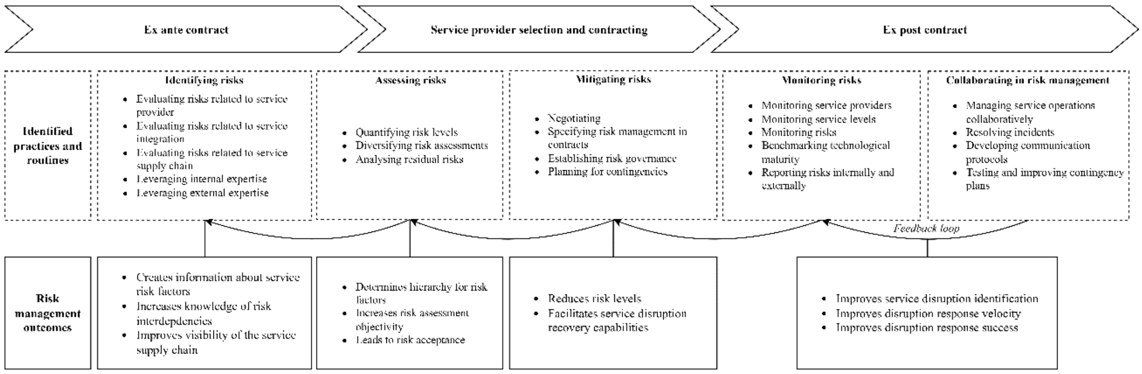


Figure 5: Findings regarding risk management practices in Publication II.

Publication II addressed a key gap in the literature by providing empirical evidence of how a financial services company may manage risks in IT service procurement. The study makes theoretical contributions by extending existing research on risk management in procurement to the context of IT services. It responded to calls for further research on the topic (Ellram *et al.*, 2008; Wynstra *et al.*, 2015), uncovering essential research gaps in the procurement research domain. Prior studies had largely focused on manufacturing and physical goods procurement, while this study expanded the understanding of risk management to include intangible services like IT.

First, we contributed by establishing a typology for risk factors in the IT service procurement context. This provides a more nuanced understanding for academics and practitioners about the complexities and uncertainties involved in IT service procurement. The analysis of risk factors expands on prior literature that has similarly considered service-related risks in various contexts (Mitchell, 1994; Ellram *et al.*, 2007, 2008; van der Valk, 2008; Wynstra *et al.*, 2015; Raddats *et al.*, 2017).

Moreover, the study provided a deeper understanding of the routines and mechanisms that can be used to manage risks in a highly specialized procurement environment. Specifically, the findings demonstrated that risk management practices in IT service procurement involve a complex interplay between formalized processes, such as risk assessments and contractual clauses, and collaborative practices, such as joint risk identification and ongoing supplier engagement. The integration of these formal and collaborative practices ensured that the focal company could manage risks effectively across all phases of the procurement process. This study focused explicitly on the buyer organization's attempts to manage risks related to service purchases, and by doing so, contribute to prior literature that had hitherto more generally discussed procurement-related activities during the service procurement process (Axelsson and Wynstra, 2002; Ellram *et al.*, 2008; Van Der Valk and Rozemeijer, 2009; Gelderman *et al.*, 2015; Raddats *et al.*, 2017; Wynstra *et al.*, 2018; Akkermans *et al.*, 2019; Pemer and Skjølsvik, 2019).

In line with practice-based view and supply chain practice view, the study proposed that the focal company enhances the performance of purchased IT services by adopting internal and collaborative risk management practices during the procurement process. 6 formal propositions were derived to suggest how service performance is affected by the identified risk factors and risk management practices. Based on the research results, risk management practices support the (1) creation of better service specifications, (2) selection of IT service providers, (3) establish optimal governance structures for service provision, (4) capacity to monitor and maintain IT service performance. Such improvements were additionally proposed to lead to increased performance for purchased IT services (P5a). In addition, we drew from the practice-based view to suggest that the identified risk factors moderate the relationship between practices and performance, as different types of contextual risks exist for different types of services (P5b). This notion is also in line with the assumption that service characteristics, and thus risks related to them, may be unique for different types of service configurations (Ellram *et al.*, 2008; Vargo and Lusch, 2008).

In line with prior literature, the study showed the importance of collaborative risk management activities with IT service providers, particularly during the ex post stage (Van Der Valk and Rozemeijer, 2009; Grudinschi *et al.*, 2014; Gelderman *et al.*, 2015). Such an approach to risk management was shown to increase service performance by enabling the focal company to gather and process more accurate and timely information about potential risks and manage service disruptions more effectively. This study also contributes by focusing on the IT services sector, which is a rarely investigated industry, and where service risks are often more complex and require more adaptive, technology-driven risk management solutions.

4.3 Publication III: Understanding the systemic sources of uncertainty for the management of greenhouse gas emissions in supply chains

Background and research objectives

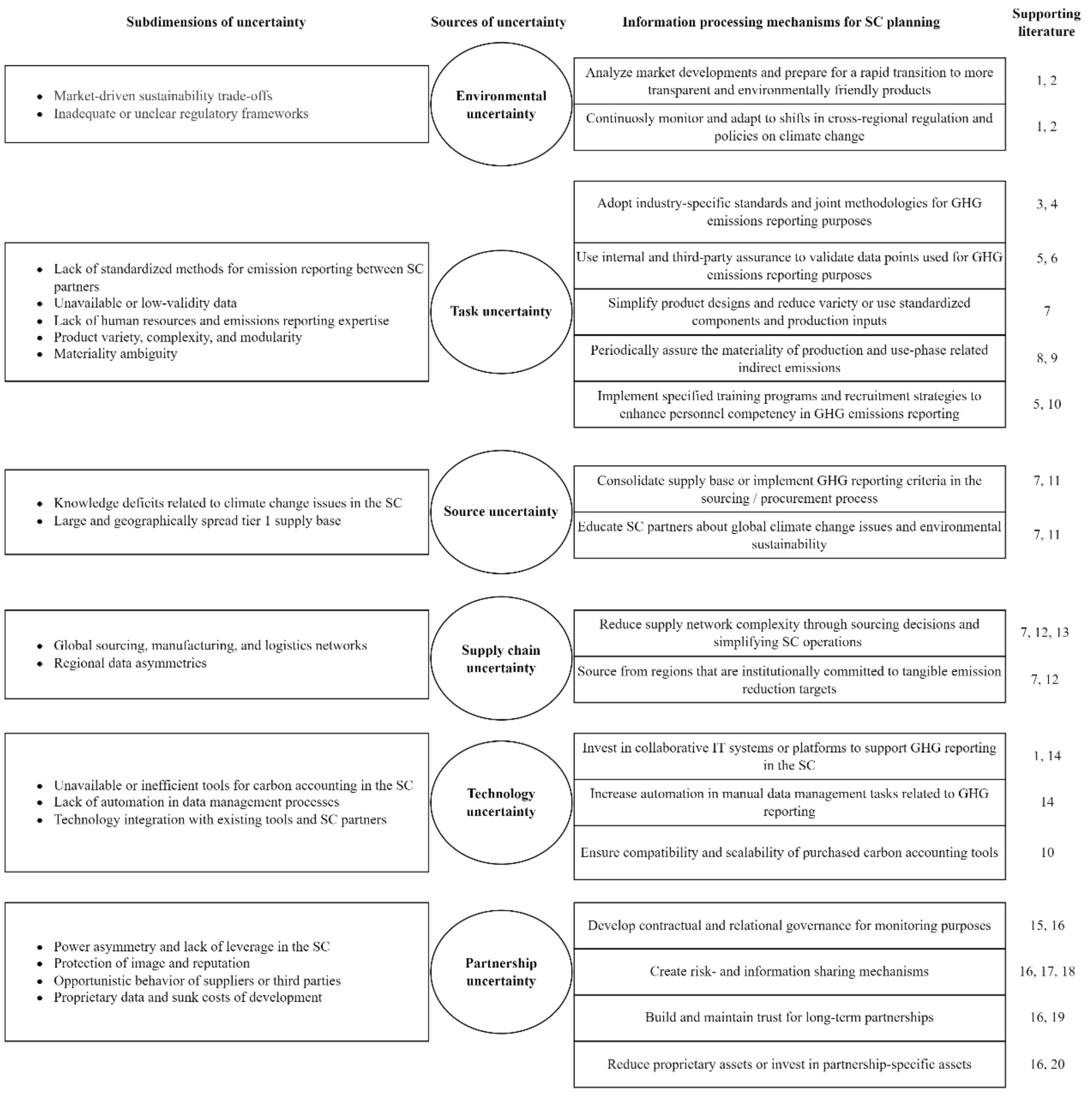
As organizations face increasing regulatory and stakeholder pressures to address climate change, the need for accurate measurement and reporting of GHG emissions across supply chains has become a critical concern (Intergovernmental Panel on Climate Change (IPCC), 2023). Scope 3 emissions, which originate from upstream and downstream supply chain activities, are particularly challenging to measure due to their indirect nature, fragmented data sources, and varying supplier capabilities (Dahlmann and Roehrich, 2019; Akhavan and Zvezdov, 2021; Vieira *et al.*, 2024). Despite growing commitments to decarbonization, many organizations struggle with information gaps, unreliable data, and the complexities of supply chain relationships, which hinder their ability to disclose emissions accurately and achieve sustainability goals. While existing research highlights the importance of addressing emissions-related uncertainties, a limited understanding remains of how specific sources of uncertainty impact emissions measurement and reporting processes in supply chains. Publication III seeks to bridge this gap by investigating the key sources of uncertainty that hinder the reliable reporting of Scope 3 emissions and exploring how organizations can enhance their information processing capabilities to address these challenges. Publication III applies organizational information processing theory to examine information needs and processing capacities to manage emissions-related uncertainties (Galbraith, 1974; Tushman and Nadler, 1978). The empirical study focuses on the steel industry, a sector facing heightened regulatory scrutiny and market expectations to achieve significant carbon reductions (Joint Research Centre, 2022; Cornwall, 2024). A qualitative research design was adopted, involving semi-structured interviews with 16 senior managers and sustainability experts from 12 European steel companies.

Publication III addresses the following research question:

How do different sources of uncertainty hinder the measurement and reporting of GHG emissions in SCs?

Main results and contributions

First, the findings of Publication III revealed how the six sources of uncertainty—environmental, task, source, supply chain, technology, and partnership uncertainty—hinder information processing in the steel supply chain's efforts to measure and report Scope 3 emissions. This was achieved by further splitting the uncertainties into 18 subdimensions, each of which contributed to specific challenges related to data collection, validation, and disclosure regarding supply chain emissions. Second, the findings of Publication III uncovered information processing mechanisms that can be implemented to mitigate the identified sources of uncertainty. The primary findings of publication III are illustrated in Figure 6.



Sources:
1. Bensaou and Venkatraman (1995); 2. Kolk an Pinkse (2005); 3. Matisoff et al. (2013); 4. Doda et al. (2016); 5. Green and Li (2011); 6. He et al. (2022) ;7. Busse et al. (2017); 8. Busch and Hoffmann (2011); 9. Eggert and Hartmann (2021); 10. Schaltegger and Csutora (2011); 11. Foerstl et al. (2018); 12. Gualandris et al. (2021); 13. De Stefano and Montes-Sancho (2023); 14. Melville and Whisnant (2014); 15. Shafiq et al. (2017); 16. Matinheikki et al. (2022); 17. Li et al. (2015); 18. Fan et al. (2017); 19. Meena et al. (2023); 20. Chen et al. (2014)

Figure 6: The primary findings of Publication III

Environmental uncertainty was found to increase due to market-driven sustainability trade-offs and inadequate regulatory frameworks. Companies struggled to balance cost-efficiency pressures with decarbonization initiatives, which diminished their commitment to accurate Scope 3 reporting. Inconsistent regulations across regions further exacerbated the issue, making it difficult for firms to standardize their emissions data collection and reporting processes. To mitigate environmental uncertainty, companies were found to adopt mechanisms such as analyzing market developments to prepare for a transition to more transparent and environmentally friendly products and continuously monitoring and adapting to evolving cross-regional climate policies to align their reporting with emerging regulatory requirements.

Task uncertainty emerged from the lack of standardized methods for emission reporting, as well as low data quality and insufficient internal expertise in carbon accounting. These challenges were most pronounced in sectors with complex product lines or varying raw material inputs, leading to higher information processing needs for emissions validation and disclosure. Organizations were forced to rely on estimation techniques, further complicating efforts to ensure accuracy. The findings suggested that these uncertainties can be mitigated by adopting industry-specific standards and joint methodologies for GHG reporting, validating data through internal and third-party assurance, and simplifying product designs to standardize inputs and reduce complexity. Additionally, firms implemented training programs and recruitment strategies to enhance internal capabilities in emissions reporting and ensure the materiality of key emissions sources.

Source uncertainty was considered especially prominent due to the geographic and operational diversity of suppliers. Knowledge deficits related to climate change and carbon management across supply chain partners increased the complexity of emissions data collection and comparison, particularly when dealing with a large, geographically dispersed supply base. Information processing mechanisms to mitigate source uncertainty was found to consist of consolidating the supply base or embedding GHG reporting criteria in procurement decisions, while also educating supply chain partners on climate change issues to improve their understanding and participation in emissions reporting efforts.

Supply chain uncertainty was driven by the complexity of global supply chain networks, where regional data asymmetries hindered the aggregation of reliable emissions data. These regional discrepancies in data readiness and accuracy led to inconsistencies in emissions reporting, which were particularly noted in logistics operations. The challenges were further exacerbated by structural complexity across supply chain tiers, making it difficult to integrate data from multiple sources. Companies sought to address these challenges by reducing supply chain complexity through sourcing decisions, simplifying operations, and prioritizing suppliers in regions with firm emission reduction targets.

Technology uncertainty was identified as a critical barrier due to the lack of available or efficient tools for carbon accounting and the limited automation in emissions data management processes. Many faced significant challenges integrating existing systems with those of their supply chain partners, particularly in handling Scope 3 emissions. The lack of robust digital solutions resulted in inefficiencies, manual data handling, and the risk of inaccurate or incomplete emissions reporting. To overcome these obstacles, companies considered it important to invest in collaborative IT systems for GHG reporting, automated manual data management tasks, and ensured compatibility and scalability of carbon accounting tools to streamline emissions tracking and reporting.

Partnership uncertainty highlighted the power asymmetry and opportunistic behavior among supply chain partners, which created risks related to incomplete or skewed emissions disclosures. The protection of proprietary data was a major concern for many companies, leading to further distrust and reluctance to share accurate greenhouse gas data. This uncertainty was especially pronounced in organizations where supplier leverage was high, making it difficult to enforce transparency and accountability. These uncertainties can be mitigated by developing contractual and relational governance mechanisms, implementing risk- and information-sharing processes, and building long-term trust-based partnerships to promote transparency and accountability in emissions reporting.

Publication III responds to multiple calls for research on supply chain emissions and contributes by advancing understanding in this increasingly important domain of research (Ellram and Tate, 2024; Vieira *et al.*, 2024; Wieland and Creutzig, 2025). The study advances the understanding of how various sources of uncertainty hinder the measurement and reporting of Scope 3 emissions in supply chains by applying organizational information processing theory. The study adopts constructs from the literature by identifying six key sources of uncertainty—environmental, task, source, supply chain, technology, and partnership uncertainty—each of which presents unique challenges to emissions-related information processing. Publication III contributes by applying a theory elaboration approach (Fisher and Aguinis, 2017) and identifying sub-dimensions related to the sources of uncertainty, and discovering information processing mechanisms to mitigate them. These findings contribute to broader literature that addresses the role of uncertainty in understanding managing supply chain emissions (Busse *et al.*, 2017; Foerstl *et al.*, 2018; Dahlmann and Roehrich, 2019; Akhavan and Zvezdov, 2021).

4.4 Publication IV: Sustainability meets service procurement: a case study in the ICT service sector

Background and research objectives

The outsourcing of services, particularly in technology-intensive sectors such as ICT, has seen rapid growth, driven by advancements in technology and a shift towards servitized business models (Tate and Ellram, 2012; Niu *et al.*, 2021). ICT services, which are integral to modern supply chain operations, differ significantly from physical goods due to their intangibility, complexity, and rapid technological evolution (Wynstra *et al.*, 2018). These characteristics create unique challenges for ensuring sustainability in the procurement of ICT services, as firms increasingly face pressures to address ESG issues across their supply chains (Hofmann *et al.*, 2020). While extensive research has examined sustainable supply management (SSM) practices in goods procurement (e.g., Vachon and Klassen, 2008; Gualandris *et al.*, 2014), comparatively little attention has been paid to the implementation of sustainability in service procurement. This gap is particularly significant in the context of ICT services, where sustainability concerns often manifest in areas such as energy consumption, greenhouse gas emissions, and e-waste management (Babin and Nicholson, 2011). Moreover, the financial sector, as a key procurer of ICT services, faces growing regulatory and stakeholder pressures to adopt sustainable practices but lacks a clear framework for evaluating and managing sustainability performance in service supply chains (European Union, 2022; Nagariya *et al.*, 2022).

To address these gaps, Publication IV examines the challenges, drivers, and practices associated with implementing sustainability in ICT service procurement. Specifically, the study investigates a Finnish firm in the financial services sector and its key ICT service suppliers to understand how sustainability is operationalized in this unique context. The research is guided by the following questions:

RQ1: What types of challenges and drivers influence the implementation of sustainable procurement in ICT service supply chains?

RQ2: What kinds of practices are used to ensure the sustainability of ICT service suppliers?

Main results and contributions

The findings of Publication IV illustrate the challenges and opportunities associated with integrating sustainability into ICT service procurement, focusing on the unique characteristics of the ICT service sector. Through a detailed case study, the publication identified several thematic challenges (Table 12), drivers of sustainable ICT procurement (Table 13) and sustainability practices of the case organization and its ICT suppliers (Table 14). Based on these findings, publication IV offers a theoretical framework (Figure 7) for ensuring sustainability in the ICT service procurement context.

First, the lack of standardization and universally accepted definitions for sustainability in ICT procurement emerged as a significant barrier. This includes challenges such as the observed absence of standardized metrics for sustainability, a lack of recognized certifications for ICT services, and varying interpretations of sustainability across stakeholders. These issues complicate efforts to develop cohesive and enforceable sustainability criteria in procurement processes. Second, the study highlighted the relatively low sustainability maturity in the ICT service sector compared to manufacturing or product-based industries. The findings reveal that sustainable practices in ICT service procurement remain in a nascent stage, with limited integration into procurement strategies and processes. Third, the intangible nature of ICT services presents distinct challenges for sustainability, including difficulties in traceability, agency problems related to service production across geographically dispersed locations, and reduced influence from customer-driven demands. The lack of physical traceability in service production processes complicates efforts to ensure transparency and accountability in the service supply chain. Post-contract monitoring also surfaced as a major challenge, as sustainability monitoring in ICT procurement often lacked clear metrics, alignment with initial supplier selection criteria, and comprehensive coverage of all suppliers, including smaller or peripheral partners. This phase is further hindered by agency problems that limit the reliability of supplier audits and sustainability assessments. Finally, technological and organizational limitations, including outdated IT systems and insufficient internal processes for supplier evaluation, were identified as critical barriers. Additionally, conflicting priorities between sustainability goals and other operational objectives, such as service performance and cybersecurity, was found to frequently undermine sustainability efforts.

Table 12: Challenges of ensuring sustainability in ICT service procurement

Theme	Challenges in ICT service procurement
Lack of standardisation and definitions	• No generally accepted definition for sustainability in ICT procurement. • Sustainability requirements are not standardised within the procurement process. • Measurement of service sustainability lacks standardisation. • Lack of recognized sustainability certifications for ICT services. • Sustainability is understood differently across departments and organisations (clients, suppliers, financial firms). • Sustainability practices vary widely across countries and regions.
Low sustainability maturity	• Sustainability is a relatively new issue in the ICT industry compared to manufacturing industries. • ICT service procurement has a lower maturity level in implementing sustainable practices compared to goods procurement.
Service characteristics	• ICT service production is intangible, involving no physical movement of goods, which complicates traceability. • Service production is often not tied to a specific geographic location, leading to potential agency problems (e.g., limited transparency on where and by whom services are produced). • Lack of direct customer contact in many ICT services reduces customer-driven influence for sustainable practices.
Post-contract monitoring challenges	• Monitoring sustainability in the post-contract stage is difficult due to a lack of clear metrics and processes. • Sustainability issues identified in monitoring are not always aligned with criteria established during supplier selection. • Sustainability monitoring tends to focus primarily on key partners, with less attention given to smaller or peripheral suppliers. • Agency problems arise during supplier audits, complicating the accuracy and reliability of sustainability assessments.
Technology and process limitations	• Outdated IT systems hinder effective sustainability tracking and reporting during the ICT procurement process. • Internal processes for evaluating and engaging suppliers on sustainability issues are often lacking or insufficient.
Conflicting priorities	• Service performance and cybersecurity concerns are often prioritized over sustainability issues, creating conflicting priorities that may undermine sustainability efforts.

Publication IV also identified key drivers that may be used to enable sustainable procurement practices in the ICT service sector, categorized into three thematic areas: stakeholder and market pressures, internal organizational capabilities, and supplier commitment and collaboration (Table 14). The first theme, stakeholder and market pressure, emerged as a critical driver for the adoption of sustainability practices in ICT procurement. Regulatory requirements compel organizations to incorporate sustainability considerations into procurement processes, while competitive pressures from industry peers encourage firms to prioritize sustainability as a strategic advantage. Additionally, sustainability is increasingly recognized as an integral part of risk management, motivating firms to address environmental and social risks within their ICT procurement practices. The second theme, internal organizational capabilities, emphasizes the pivotal role of organizational expertise and commitment in advancing sustainable procurement. The findings reveal that procurement employees' knowledge and proactive involvement significantly enhance the adoption of sustainability practices. Moreover, the dissemination of sustainability knowledge within the organization fosters a culture that prioritizes environmental and social considerations. Strong management commitment is another essential enabler, providing the necessary support and resources to implement sustainability initiatives throughout the procurement lifecycle. The third theme, supplier commitment and collaboration, underscores the importance of suppliers in driving sustainable ICT procurement. The study highlights that suppliers with higher sustainability maturity facilitate the buyer organization's ability to adopt sustainable practices. Additionally, proactive supplier-led sustainability initiatives and education efforts were found to strengthen the integration of sustainability into procurement. Key suppliers often act as partners in sustainability and offer guidance on best practices and co-developing sustainability strategies with their clients.

Table 13: Drivers of sustainable ICT procurement

Theme	Drivers of sustainable ICT procurement
Stakeholder and market pressure	• Regulatory pressure encourages the adoption of sustainability practices in ICT procurement. • Competitive pressure from industry peers motivates firms to prioritize sustainability in procurement to remain competitive. • Viewing sustainability as a component of risk management encourages firms to integrate sustainable practices into ICT procurement.
Internal organisational capabilities	• Expertise and proactive involvement of procurement employees drive the implementation of sustainable procurement practices. • The procurement department actively disseminates sustainability knowledge within the organisation, fostering a culture of sustainability. • Management commitment supports the adoption and enforcement of sustainability initiatives throughout the procurement process.
Supplier commitment and collaboration	• Higher sustainability maturity among suppliers supports sustainable practices, making it easier for the buyer organisation to adopt and enforce such practices. • Proactive sustainability initiatives led by suppliers drive the integration of sustainability in ICT procurement. • Key suppliers provide guidance and education to client firms on effective sustainability management practices.

Publication IV identified a comprehensive set of sustainability practices that organizations can adopt to enhance the sustainability of ICT service procurement processes. These practices were categorized into three thematic areas: requirements, monitoring, and collaboration (Table 14). The first theme, requirements, focuses on establishing sustainability criteria as a baseline for supplier engagement. The study highlights the use of codes of conduct to enforce environmental, social, and governance (ESG) expectations during supplier selection. Requiring suppliers to disclose service production processes and supply chain details ensures transparency and alignment with sustainability objectives. Furthermore, the inclusion of sustainability requirements in supplier contracts formalizes these commitments and drives accountability. Client-driven sustainability demands, such as ESG questionnaires and performance targets, also play a critical role in motivating suppliers to adopt sustainable practices. The second theme, monitoring, highlights the importance of assessing and tracking supplier performance against sustainability metrics. Due-diligence interviews with supplier employees help evaluate social sustainability themes, while monitoring efforts are often concentrated on key suppliers to assess critical indicators such as CO2 emissions, occupational well-being, and diversity. Sustainability-related reporting by suppliers enhances transparency and facilitates collaborative monitoring. Additionally, organizations supplement supplier-provided information with independent sources, such as media reports, to verify claims and address potential risks. However, the study also identifies limitations in monitoring smaller or peripheral suppliers, often due to outdated IT systems that hinder automation and scalability. The third theme, collaboration, emphasizes the value of building strong partnerships with key suppliers to address sustainability challenges proactively.

Governance programs with main suppliers, involving regular meetings and dedicated vendor leads, provide structured platforms for resolving sustainability issues. Furthermore, the allocation of dedicated resources for supplier partnerships and collaborative problem-solving promotes deeper engagement and supports the resolution of sustainability-related challenges.

Table 14: Sustainability practices in ICT service procurement

Theme	**Sustainability practice**	**Description**
Requirements	Enforcing sustainability criteria through codes of conduct	Establishing a foundation for sustainability by requiring suppliers to accept codes of conduct, which outline environmental, social, and governance expectations, especially during supplier selection.
	Requiring disclosure of service production processes in the supply chains	Mandating transparency from suppliers regarding their service production processes and supply chains to ensure alignment with sustainability goals.
	Including sustainability requirements in supplier contracts	Integrating sustainability commitments into formal contracts to drive compliance and accountability throughout the procurement process.
	Responding to increasing client-driven sustainability demands	Adapting to growing client requirements for sustainability, such as ESG questionnaires in tenders and specific performance targets for sustainability initiatives.
Monitoring	Conducting due-diligence interviews with suppliers	Assessing social sustainability themes through interviews with suppliers' employees.
	Focusing monitoring efforts on key supplier partners	Concentrating resources on strategic suppliers to monitor critical sustainability metrics, including CO2 emissions, occupational well-being, and diversity indicators.
	Requiring sustainability-related reporting	Requesting suppliers to provide detailed reports on sustainability indicators to enhance transparency and support collaborative monitoring efforts.
	Using media and external sources to verify supplier claims	Supplementing supplier-provided information with independent sources such as media and news outlets to identify and address potential sustainability risks.
	Enhancing supply chain visibility	Improving visibility into smaller critical suppliers beyond major partners to mitigate reputational risks.
	Acknowledging limitations due to outdated IT systems	Recognizing that outdated IT systems hinder automation and scalability of sustainability monitoring, particularly for smaller or less strategic suppliers.
Collaboration	Leveraging governance programs with main suppliers	Utilizing structured governance programs with key suppliers, involving regular meetings and dedicated vendor leads to address and resolve sustainability issues proactively.
	Allocating resources for partnerships and issue resolution	Assigning a dedicated team to monitor key supplier relationships, resolve sustainability challenges, and foster collaborative problem-solving efforts.

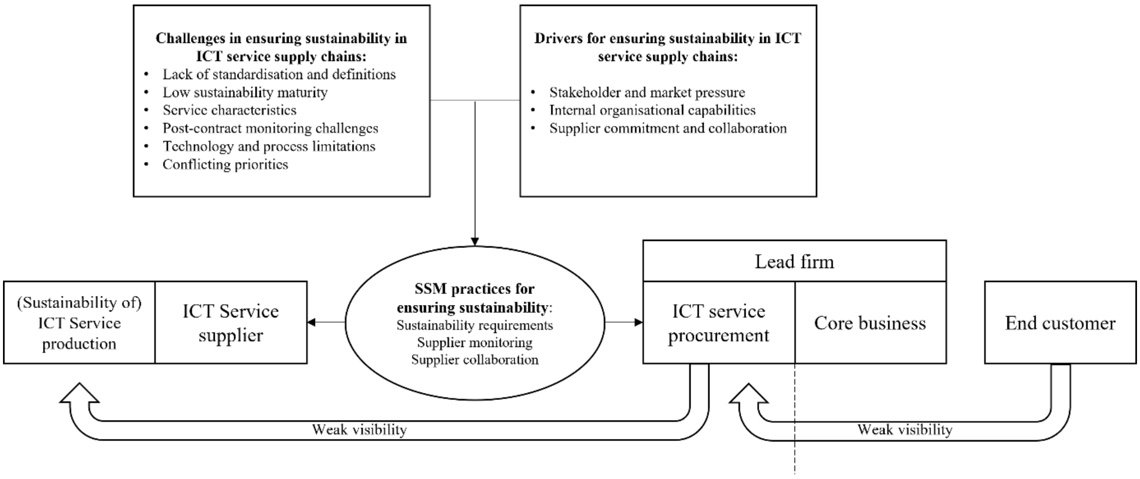


Figure 7: Theoretical framework of ensuring sustainability of ICT service supply chains

Publication IV provides a novel framework for understanding sustainability in ICT service procurement, emphasizing the interconnectedness of challenges, drivers, and practices across ICT service supply chains (Figure 7). This study makes three main contributions. First, it highlights the unique challenges associated with ensuring sustainability in ICT services, including the lack of standardization, service-specific complexities, and limited visibility into supply chains. For instance, unlike manufacturing supply chains where certifications and standardized sustainability criteria are widely used (Klassen and Vachon, 2003; Marshall *et al.*, 2015), the findings reveal a significant gap in standardization and certifications tailored to ICT services. This gap complicates sustainability assessments and hinders firms' ability to monitor supplier compliance effectively. The research shows the need for tailored sustainability frameworks to address these challenges, especially given the intangibility, flexibility, and rapid technological advancements in ICT services (Erramilli and Rao, 1990; Di Gregorio *et al.*, 2009). Second, the study identifies internal and external drivers of sustainability in ICT service procurement, advancing the literature on sustainable supply management by extending its focus to services. Unlike product-based procurement, where consumer advocacy is a strong driver (Meixell and Luoma, 2015), this research finds that internal organizational capabilities—such as the expertise and proactive involvement of procurement employees—play a pivotal role in the absence of significant consumer pressure. These findings align with prior research highlighting the importance of internal stakeholder commitment in driving sustainability initiatives (Ehrgott *et al.*, 2011). Furthermore, suppliers emerge as critical influencers in ICT service supply chains, offering advanced sustainability capabilities and educating buyers on sustainability practices, reinforcing the collaborative potential of buyer-supplier relationships (Andersen and Skjoett-Larsen, 2009). Third, this research identifies sustainability practices tailored to the ICT service context, building on existing SSM literature. While enforcing sustainability criteria through codes of conduct was found to be a common practice consistent with previous studies (Vachon and Klassen, 2006; Awaysheh and Klassen, 2010), practices such as structured supplier collaboration and governance programs take on heightened importance in service supply chains. These practices help address the visibility challenges and agency problems unique to ICT services, such as the reliance on non-geographically bound service providers and the limited traceability of service delivery processes (Gruchmann, 2022).

5 Discussion and conclusions

This dissertation investigated how digitalization affects organizations' ability to manage risks and enhance resilience in supply chains. The findings from the four publications collectively demonstrate that digitalization contributes to reducing uncertainty by improving information processing performance (Publications I & III), while a better understanding and management of technology service-related risks also play a crucial role in resilience (Publications II & IV). Reducing uncertainty is essential for managing risks and disruptions, addressing sustainability-related challenges, and, in turn, strengthening supply chain resilience. This section provides answers to the research questions by drawing key insights from each publication. Finally, it discusses implications for theory and practice, as well as the study's limitations and directions for future research.

5.1 Answering the research questions

This dissertation identified three distinct research gaps related to digitalization and its relationship with supply chain risk management and resilience. This dissertation conducted four empirical investigations to bridge these research gaps. The main research question was: *how does digitalization affect organizations' capacity to manage risks and increase resilience in their supply chains*. Figure 8 and Table 15 summarize the results and shows how each publication is connected to the main research question.

First, the findings obtained in Publication I suggest that procurement digitalization enhances the information processing performance in supply chains by increasing the capacity to collect, share, analyze, and act on procurement and upstream supply chain-related data. Improved information processing in the supply chain reduces uncertainty, predicting an organization's ability to better manage supply chain risks and disruptions (Fan *et al.*, 2017). Thus, procurement digitalization was found to contribute to supply chain resilience by improving the ability to respond to unpredictable events. Second, Publication II highlights that the procurement and implementation of IT services introduce unique risk factors for organizations and their supply chains. Managing risks of technology purchases is important to support the stability of digital support systems for business operations and managing the supply chain (Ghadge, Weiß, *et al.*, 2020). The implementation of risk management practices during procurement processes for IT services is found to mitigate risks specifically related to technologies and also prepares organizations in the service relationship to manage sudden disruptions collaboratively. A reduction in risk levels and an improved capacity to manage them through the investigated practices manifests as reduced uncertainty for the service buyer and its suppliers. Altogether, the findings evidence that the ability to manage risks, proactively prepare for disruptions, and also learn from them may increase resilience. As such, these findings serve as a plausible explanation as to how the resilience of supply chains can be improved during the implementation of digitalization in supply chains. Third, Publication IV extended on risk management considerations in ICT service procurement by exploring how organizations can manage sustainability performance of ICT service suppliers.

Managing sustainability is an essential aspect of risk management for technology service buyers, as IT service provision is closely linked to social and environmental concerns, including issues such as human rights, labor practices, and resource consumption. Publication IV identifies various challenges that complicate the ensuring of sustainability. Practices such as enforcing sustainability requirements, enhancing monitoring mechanisms, and promoting supplier collaboration mitigate these risks while improving service visibility and compliance with sustainability goals. These mechanisms reduce uncertainty related to the sustainability of ICT service suppliers and their service production processes, and by doing so ensure that organizations are better equipped to manage potential sustainability-related risks, such as reputation loss or adverse supplier selection (Ellram *et al.*, 2008; Wynstra *et al.*, 2015). Fourth, Publication III found evidence that information processing related to supply chain emissions can be hindered by several sources of uncertainty. In practice, many such sources are related to perceived challenges in the use of management information systems and data-driven practices with suppliers, which may have a major role in amplifying uncertainties related to environmental sustainability for organizations and their supply chains (Melville and Whisnant, 2014; Ellram and Tate, 2024). Additionally, mechanisms to improve information processing were uncovered, which are linked to information processing practices to reduce the uncertainty associated with supply chain emissions. Publication III elaborates how a better understanding of the sources of uncertainty and mechanisms to reduce their effect may benefit organizations in managing particularly environmental sustainability-related risks and disruptions, which can manifest as either operational breakdowns, financial losses, ecological disruptions, or a combination of these factors. This improved ability is connected to enhanced supply chain resilience, which involves also systematic considerations regarding how supply chain-driven disruptions may affect also social-ecological systems, their negative feedback effects, and how to manage them effectively.

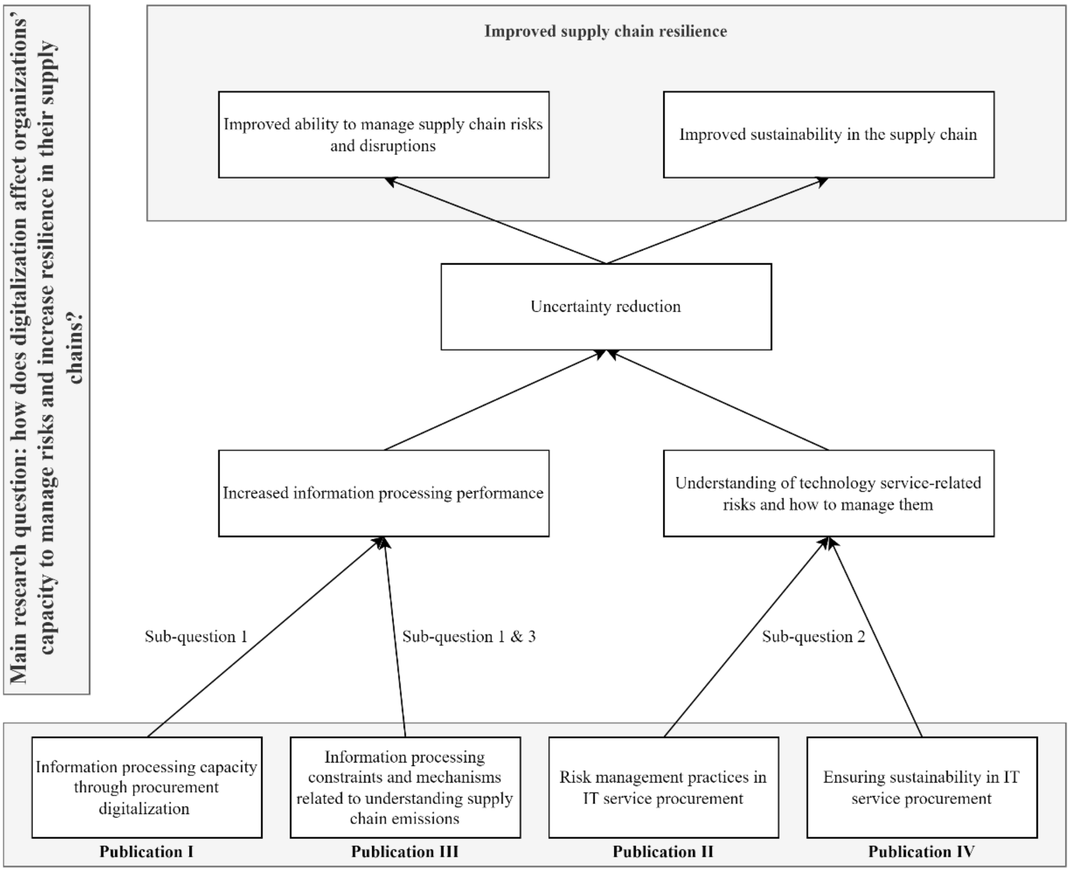


Figure 8: Summary of the results and how they contribute to the research questions

Sub-question 1: How does procurement digitalization impact supply chain resilience?

Procurement digitalization was found to impact supply chain resilience by enhancing information processing capacities within procurement functions. Specifically, digital maturity in procurement processes and the use of data analytics facilitate improved information sharing with supply chain partners, which strengthens risk management practices and ultimately contributes to resilience (Publication I). The results indicate that as procurement functions increase their level of digitalization, their capacity to manage and respond to risks is expected to improve. This is explained by the optimization of information flows and generation of data-driven insights, through which procurement digitalization enables more proactive and responsive risk management strategies, which are vital for maintaining resilience in the face of disruptions (Srai and Lorentz, 2019). Additionally, technologies and technology-related practices that support the measurement and sharing of emissions-related information in the upstream supply base were shown to reduce sustainability-related risks and contribute to decarbonization efforts (Publication III). This also has a positive impact on supply chain resilience by mitigating sustainability-related supply chain risks, such as reputational risks (Blanco, 2021) and ecological disruptions (Sodhi and Tang, 2021; Wieland, 2021).

Sub-question 2: How can organizations manage risk and resilience during the process of acquiring and implementing technology solutions?

Prior research suggests that strategies for managing risk may differ between those traditionally applied in the procurement of physical goods and those applied in service procurement contexts (Ellram *et al.*, 2008; Wynstra *et al.*, 2015). This research demonstrates that the acquisition and implementation of technology services may introduce unique risk factors that require tailored risk management strategies. IT services were found to pose challenges due to dependencies on service providers, suboptimal processes and governance for risk management, and vulnerabilities in technology utilization and service provision. Simultaneously, this research uncovered that managing the sustainability of purchased IT services may be challenging, which introduces sustainability-related risks. Effective risk management in IT service procurement was found to involve the integration of formalized risk management routines, such as risk identification, contractual safeguards, and governance structures, throughout the procurement process (Publication II). Additionally, the study highlights the importance of close collaboration with service providers during both the acquisition and implementation phases to mitigate risks related to service continuity, cybersecurity, and performance stability. Such collaborative approaches are argued to ensure the resilience of digital service operations and their contribution to the stability and performance of broader supply chain activities, which increasingly rely on IT services for coordination and management (Ghadge, Weiß, *et al.*, 2020; Van Hoek, 2020). Publication IV further addresses this sub-question by emphasizing the role of sustainability as an integral part of risk management in ICT service procurement. The study highlights how challenges such as the intangibility of services, the lack of standardized sustainability criteria, and limited visibility into supply chains amplify sustainability-related risks in this context. Managing these risks requires organizations to adopt practices that go beyond traditional risk management approaches, including sustainability-focused governance, supplier collaboration, and enhanced monitoring mechanisms. Furthermore, addressing sustainability risks aligns with evolving regulatory frameworks (such as CSRD), which increasingly require organizations to ensure sustainability within their ICT service supply chains. Managing such sustainability risks yields reduced uncertainty for the service buyers, contributing to increased supply chain resilience in the form of better operational continuity of purchased IT services, as well as more ecologically resilient IT service supply chains.

Sub-question 3: How can information processing address challenges associated with different sources of uncertainty that hinder sustainability in supply chains?

Research suggests that low information processing capacity within and between organizations may result in increased vulnerability to various supply chain risks (Fan *et al.*, 2017). Recently, research has increasingly emphasized the role of information processing in managing environmental sustainability in supply chains (Dahlmann and Roehrich, 2019; Akhavan and Zvezdov, 2021; De Stefano and Montes-Sancho, 2024). This research found that managing GHG emissions in supply chains involves significant information processing challenges due to various sources of uncertainty. Publication III identifies several categories and subdimensions of uncertainty that complicate emissions measurement and reporting between organizations. It was found that effective information processing mechanisms are critical for addressing these uncertainties. This research also found that many information processing needs and mechanisms for addressing these challenges are related to technology use and data-driven practices. In practice, it can be argued that without technological systems and data-driven management supply chain emissions are almost impossible to grasp, and as a result, effective carbon management initiatives may be difficult to implement. By improving information processing capabilities, this research suggests that organizations can better manage the complexities associated with emissions measurement and disclosure in supply chains, ultimately supporting their sustainability goals and resilience against climate change-related disruptions. This also facilitates a more efficient transition toward decarbonization and the implementation of more sustainable supply chain practices (Vieira *et al.*, 2024).

Table 15: How the dissertation research answers the research questions

Research question	Key findings from each publication
Main research question: How does digitalization affect organizations' capacity to manage risks and increase resilience in their supply chains?	- Digitalization in procurement processes enhances information processing performance, which helps organizations to manage risks and increase resilience in the supply chain (Publication I, Publication III). - Digitalization may introduce unique risk factors, which require collaborative approaches to risk management during the procurement process and subsequent service management. Disruptions in digital services can affect broader supply chain operations (Publication II). - Digitalization requires organizations to adopt sustainability-focused governance practices, supplier collaboration, and monitoring mechanisms to mitigate sustainability-related challenges in ICT service supply chains. These mechanisms help organizations reduce uncertainty associated with sustainability, which contributes to supply chain resilience (Publication IV). - Technologies and technology-related practices increase information processing performance and support the management of sustainability-related risks, such as those related to GHG emissions in supply chains, which are increasingly seen as crucial for supply chain resilience (Publication III).
Sub-question 1: How does procurement digitalization impact supply chain resilience?	- The digital maturity of procurement processes and the use of data analytics in procurement contribute to information sharing, which positively affects risk management and resilience in the supply chain (Publication I). - The improved capability to manage risks and resilience is facilitated by the improved information processing capacity, which is related to higher digitalization level in procurement functions (Publication I). - Technologies and technology-related practices that help to measure and share information on emissions related to the upstream supply base reduce sustainability related risks and support decarbonization efforts (Publication III).
Sub-question 2: How can organizations manage risk and resilience during the process of acquiring and implementing technology solutions?	- IT service procurement introduces multiple risk factors that require distinct risk management strategies compared to the procurement of goods (Publication II and IV). - Integrating risk management practices into the procurement process supports controlling technology-related risks during the acquisition, implementation, and management of technology services (Publication II). - IT service procurement demands close collaboration with service providers to manage risks (Publication II and Publication IV). - Sustainability is a critical consideration in IT service procurement, as the sustainability of service provision introduces risks related to social and environmental issues. Addressing these risks requires organizations to implement sustainability-focused governance practices, which collectively contribute to uncertainty reduction and resilience in ICT service supply chains (Publication IV).
Sub-question 3: How can information processing address challenges associated with different sources of uncertainty that hinder sustainability in supply chains?	- Several sources of uncertainty, which are composed of unique sub-dimensions, complicate information processing related to supply chain emissions (Publication III). - Specific information processing mechanisms are essential to effectively manage the sources of uncertainty related to Scope 3 emissions (Publication III). - Enhanced information processing capabilities support GHG emissions measurement and reporting in supply chains, which is critical for achieving sustainability goals, decarbonization, and managing sustainability-related risks (Publication III).

5.2 Theoretical contributions

This dissertation offers contributions mainly to the literature on supply chain risk management and supply chain resilience by applying the organizational information processing theory and practice-based theories. By addressing the current challenges posed by digitalization and sustainability pressures, the research advances understanding of how information processing related to procurement and supply chain emissions, and risk management practices related to IT service procurement are related to reduced uncertainty. By doing so, the findings apply existing theories and provide a more nuanced and contemporary understanding of current challenges related to risk management and resilience in supply chains. The remainder of this section discusses the dissertation research's implications in the context of (1) organizational information processing theory, (2) practice-based theories, and (3) the broader literature on risk management and resilience in supply chains.

5.2.1 Implications for organizational information processing theory

This dissertation advances the application of OIPT by demonstrating how digitalization enhances the capacity of supply chains to process information, thereby reducing uncertainty and improving resilience. OIPT posits that organizations must balance their information processing needs and capacities to manage uncertainty effectively (Galbraith, 1974). This research elaborates on how digital technologies and data-driven practices are predicted to serve as critical enablers in achieving this balance, particularly in complex supply chain contexts where risks may be multifaceted and dynamic.

In the context of procurement, this dissertation shows that digitalization promotes alignment between information demands and processing capabilities by enabling real-time data sharing, advanced analytics, and seamless communication across upstream supply chain partners. Thus, the empirical findings contribute to research arguing that information processing, particularly through technology-driven information systems, has a positive impact on the capacity to manage risks and resilience in supply chains (Fan *et al.*, 2017; Fischer-Preßler *et al.*, 2020; El Baz and Ruel, 2021). This also aligns with prior research stating that technology use provides firms with the tools to respond more effectively to disruptions for example, by enhancing visibility and forecasting accuracy (Premkumar et al., 2005; Ivanov et al., 2019).

This research also broadens OIPT's scope by integrating sustainability-related challenges into the information processing framework. Managing supply chain emissions introduces significant information processing challenges due to the fragmented and uncertain nature of emissions data across supply chain tiers (Dahlmann and Roehrich, 2019; Akhavan and Zvezdov, 2021; De Stefano and Montes-Sancho, 2024). This dissertation identifies six specific sources of uncertainty that exacerbate the difficulty of measuring and reporting supply chain emissions. By mapping these uncertainties to their subdimensions, the research offers a more granular understanding of the associated challenges, their potential negative effects and how information processing mechanisms, such as data standardization, collaborative platforms, and real-time monitoring systems, can alleviate these challenges. The dissertation therefore contributes to a better understanding on how the sources of uncertainty may negatively affect information processing to manage decarbonization through (1) climate change engagement in supply chains (Dahlmann and Roehrich, 2019), (2) resolving supply chain complexity (De Stefano and Montes-Sancho, 2024), and (3) implementation of data-driven practices, such as analytics (Balci and Ali, 2024). These findings also contribute to calls for further research on how data quality issues and coordination challenges between supply chain partners can be facilitated through improved information processing (Ellram and Tate, 2024; Vieira *et al.*, 2024).

Thus, a broader implication of this research is that organizations equipped with robust digital infrastructures and data-related practices can better align their information needs with capacities and enables them to anticipate various disruptions and coordinate responses in their supply chain risk management. However, this research importantly extends the application of information processing to also manage systemic risks related to environmental sustainability in supply chains. These insights elaborate on how information processing contributes to a more holistic understanding of supply chain resilience, which includes managing sustainability and social ecological systems-based risks (Sodhi and Tang, 2021; Wieland, 2021; Intergovernmental Panel on Climate Change (IPCC), 2023; Holgado *et al.*, 2024).

5.2.2 Implications for practice-based theories

This dissertation contributes to practice-based theories, including the PBV and SCPV, by elaborating on how risk management practices may be operationalized to address specific challenges within the context of IT service procurement. Practice-based theories emphasize the routines and practices organizations adopt to achieve performance (Bromiley and Rau, 2014; Carter *et al.*, 2017). In general, there seems to be a limited amount of research explicitly applying the practice-based theories to explain performance variation related to procurement practices, and especially so from a risk management perspective.

Formal practices, such as the use of contractual safeguards and structured risk assessments, were shown to play a critical role in ensuring service continuity and mitigating vulnerabilities from the buyer organization's perspective. This builds upon research arguing that mechanisms like service-level agreements, performance metrics, and penalty clauses are instrumental in defining expectations and mitigating risks during both the pre-contractual and operational phases of service provision (Ellram *et al.*, 2008; Akkermans *et al.*, 2019). The risk management perspective taken in the research deepens this understanding by differentiating such routines from practices and elaborates how they must be properly sequenced to achieve an effective control of over service risks.

In parallel, collaborative practices were found to be essential for addressing risks that cannot be fully managed through formal mechanisms alone. For example, joint risk monitoring, open communication channels, and co-development of contingency plans with service providers foster relational trust and enable firms to respond more adaptively to emerging risks. This relational dimension complements formal practices by facilitating real-time information sharing and collective problem-solving, thereby addressing risks that require dynamic and context-sensitive responses. By differentiating and elaborating the use of relational risk management practices, this research contributes to broader literature on the role of collaboration in service procurement and its effect on managing service performance (Gelderman *et al.*, 2015; Raddats *et al.*, 2017).

The findings of this research illustrate how organizations may employ a combination of formalized and relational practices to manage service risks. However, an interesting question remains how service performance may be exactly facilitated by the implementation of practices. In line with the practice-based theories, this research proposes that service performance gains are achieved through the reduction of operational service risks and disruptions that diminish service levels. Also, the research found managing the continuity and resilience of services is greatly influenced by risk management practices. Based on these insights, the research proposed that the relationship between risk management practices and service performance should be moderated by the risk factors that are associated with a specific IT service purchase. In general, these findings contribute to a nascent understanding of the practice-performance link specifically in the context of risk management and service procurement (Ellram *et al.*, 2008; Wynstra *et al.*, 2015).

Due to the IT service procurement context, it can be tentatively maintained that risk management practices during technology procurement processes may also enhance the stability of digital service operations by addressing challenges unique to intangible and technology-dependent services. This suggests wider implications also on the practice-performance link regarding digitalization in supply chains, especially when technology services to support supply chain operations are outsourced (Ghadge, Weiß, *et al.*, 2020).

5.2.3 Implications for the broader literature on supply chain risk management and resilience

This dissertation also makes contributions to the broader literature on supply chain risk management and supply chain resilience by integrating concepts of digitalization, risks of digitalization, and sustainability to explore how organizations can navigate an increasingly complex and uncertain business environments. For example, an implicit assumption supported by prior research is that technologies and data-driven practices enable organizations to improve their ability to mitigate and respond to disruptions (Fischer-Preßler *et al.*, 2020). By examining evidence from four novel perspectives, the findings of this dissertation support the general understanding that technologies are connected to better risk management and resilience in supply chains (Fan *et al.*, 2017; Fischer-Preßler *et al.*, 2020; El Baz and Ruel, 2021; Zouari *et al.*, 2021). The findings provide an improved understanding of how organizations can manage risks and enhance resilience by addressing the interplay between information flows, risk management practices, and the increasing sustainability pressures of modern supply chains. Subsequently, empirical research on this has been called for further research by multiple accounts (Van Hoek, 2020; Ellram and Tate, 2024; Holgado *et al.*, 2024; Vieira *et al.*, 2024).

First, the role of the procurement function in managing upstream supply chain risks has been widely established in prior research (Zsidisin *et al.*, 2000, 2004). This perspective has been since further developed from the standpoint of technology and information systems use as basis for increasing the effectiveness of procurement (Davila and Gupta, 2003; Trkman and McCormack, 2010). The general principle behind such advantages is arguably a better understanding of data, which allows increased more effective integration between suppliers, buyer organization and their inter-dependent supply chain processes (Handfield *et al.*, 2019). More recently, the advanced digitalization of the procurement function has discussed, for example, how to implement it, what type of technologies and practices are useful, and how it is related to the value drivers of procurement in an organization (Kosmol *et al.*, 2019; Srai and Lorentz, 2019; Seyedghorban *et al.*, 2020; Lorentz *et al.*, 2021). Hitherto, a limited amount of empirical research has contributed to this discussion by specifically investigating aspects of procurement digitalization and how it is connected to managing risks and performance in supply chains (Bag *et al.*, 2020; Viale and Zouari, 2020; Hallikas *et al.*, 2021). Therefore, this research contributes to this stream literature by specifically assessing the relationship of data analytics, information sharing and digital maturity in procurement, and how it predicts resilience in supply chains.

Second, this dissertation also explores the potential risks introduced by digital transformation in supply chains. For example, cyberattacks, technology failures, and dependency on technology service providers create vulnerabilities that traditional risk management practices are often ill-equipped to address (Ghadge, Weiß, et al., 2020; Kessler et al., 2022). The dissertation accounts for multiple potential risk factors during the procurement process for technology services, and the practices to manage them. Additionally, it expands this understanding by addressing how sustainability-related challenges inherent to the procurement technology services can be managed. By doing so, this dissertation contributes to the literature by investigating how sustainability can be incorporated as a key risk management consideration in the procurement of technology services, for example, to prevent reputational risks for the service buyer (Wynstra *et al.*, 2015). Thus, the insights provided in this dissertation position digitalization as both an enabler and a challenge for supply chain resilience. These findings contribute to literature discussing this dichotomy (Tupa *et al.*, 2017; Ghadge, Weiß, *et al.*, 2020; Kessler *et al.*, 2022), providing evidence of potential antecedents, causal mechanisms and practices to diminish risk levels related to technology outsourcing in supply chains.

Third, this dissertation seeks to incorporate environmental sustainability risks into the concept of resilience. It does so by considering the effects of sustainability-driven risks on performance and ecological systems in which supply chains are embedded in, which relates to the growing scholarly discussion on the complex systems-based, social-ecological resilience in supply chains (Wieland, 2021; Holgado *et al.*, 2024). Sustainability-related risks, particularly those linked to greenhouse gas emissions and climate change, are becoming increasingly significant as organizations face regulatory, reputational, and operational pressures (Blanco, 2021; Intergovernmental Panel on Climate Change (IPCC), 2023; Vieira *et al.*, 2024). Sustainability risks, such as those arising from Scope 3 emissions, are found to often involve high levels of uncertainty due to inconsistent data quality, fragmented regulatory environments, and challenges in supplier engagement. The findings demonstrate how organizations can improve their ability to manage these uncertainties through enhanced information processing mechanisms. Therefore, this dissertation responds to calls for further research and contributes to these discussions by extending the scope of resilience to include the need to manage sustainability risks proactively to ensure long-term operational performance while simultaneously preventing systemic social-ecological risks related to climate change (Wieland, 2021; Ellram and Tate, 2024; Holgado *et al.*, 2024; Vieira *et al.*, 2024).

5.3 Practical implications

The findings of this dissertation offer insights for practitioners in supply chain management, procurement, and sustainability, particularly in navigating the dual pressures of digitalization and sustainability. These practical implications are relevant for managers seeking to enhance their organizations' risk management capabilities, strengthen supply chain resilience, and improve sustainability outcomes.

First, organizations should prioritize investments in procurement digitalization to improve supply chain resilience. This research highlights that tools such as data analytics and real-time information systems enable better information sharing and decision-making, which are critical for identifying and mitigating risks. Managers should focus on implementing advanced technologies that support information sharing with suppliers, improve visibility across supply chain tiers, and enhance risk management practices. Moreover, training procurement teams to effectively use digital tools can amplify these benefits and ensure that the organization fully leverages its technological investments.

Second, the findings argue for the importance of integrating formal and collaborative risk management practices throughout the IT service procurement process. Managers should adopt a structured approach to risk identification, assessment, and mitigation, utilizing tools such as contractual safeguards and performance metrics. Simultaneously, promoting close collaboration with IT service providers is essential for ensuring service continuity, particularly in addressing risks related to cybersecurity, service disruptions, and operational dependencies. Firms should establish regular communication protocols and joint contingency plans with their service providers to build trust and enhance adaptive responses to emerging risks.

Third, the findings emphasize the need for organizations to adopt tailored approaches to managing sustainability in ICT service procurement. Managers should prioritize the development and implementation of standardized sustainability criteria, including clear

ESG requirements, within supplier selection processes and contracts to address sustainability challenges effectively. Enhancing visibility across the service supply chain is equally important, particularly for smaller or less prominent suppliers. Additionally, fostering collaborative relationships with ICT service suppliers through structured governance programs, such as regular sustainability reviews and joint initiatives, can strengthen the alignment of sustainability goals and improve long-term outcomes. As regulatory demands become more stringent, managers should proactively integrate sustainability into procurement practices, positioning their organizations as leaders in sustainable ICT service procurement and ensuring resilience against sustainability-related risks in ICT service supply chains.

Fourth, sustainability-related risks, particularly those associated with Scope 3 emissions, require robust information processing mechanisms to manage the inherent uncertainties in emissions measurement and reporting. Managers should focus on developing standardized data collection and reporting frameworks, investing in digital platforms that facilitate collaboration across the supply chain, and aligning their emissions reporting practices with regulatory and stakeholder expectations. By enhancing their ability to process sustainability-related information, organizations can not only improve their risk management capabilities but also strengthen their resilience against climate-change-driven disruptions.

5.4 Limitations and future research directions

First, while the quantitative approach in Publication I enabled generalizable insights, the reliance on cross-sectional data limits the ability to capture dynamic, temporal changes in the relationships studied. Procurement digitalization is an evolving process, and its long-term effects on resilience might vary as organizations adopt new technologies and refine existing practices. Future research could address this limitation by employing longitudinal designs to observe changes over time. The conceptual model in Publication I relied on self-reported measures of digitalization, information sharing, risk management, and resilience. While validated scales were employed, the use of self-reported data may introduce bias or subjectivity. Future research could incorporate objective data, such as performance metrics or digital system usage logs, to strengthen the validity of the findings. Additionally, expanding the geographical scope beyond Finland would help generalize the conclusions across more diverse industrial contexts.

Second, the single-case study design in Publication II may constrain the generalizability of the findings. The risks and practices identified may not fully capture the complexities of IT service procurement in other sectors, such as manufacturing or healthcare, where different regulatory, technological, and market dynamics may apply. Future research should replicate the study across multiple industries and organizations to validate and extend its findings. Publication II focuses on IT service procurement without fully exploring how service characteristics, such as complexity or standardization, influence risk management practices. Services with higher levels of customization or technological complexity may require distinct approaches to risk identification, assessment, and mitigation. Future studies could examine how variability in service configurations impacts the effectiveness of risk management practices across different service procurement contexts. While the findings highlight the importance of collaboration with IT service providers, Publication II provides limited insight into the long-term evolution of these relationships. Understanding how collaboration matures over time and its impact on resilience in service procurement is a promising avenue for future research.

Third, while Publication III provides much-needed insights into environmental sustainability-related risks, it narrows the scope of inquiry to a single environmental dimension. Future research could broaden the investigation to include other sustainability challenges, such as social and governance risks, which are increasingly integral to supply chain management, and often related to climate change-related risks. Publication III employs a qualitative research design, based on interviews with stakeholders in the European steel supply chain, which may limit the generalizability of its findings. The sources of uncertainty identified and their impact on information processing might vary significantly across industries with different levels of emissions complexity, regulatory pressures, and supply chain structures. Expanding the research to sectors such as agriculture, textiles, or electronics could provide a more comprehensive understanding of emissions-related uncertainties. While Publication III discusses the role of digital technologies in addressing emissions-related uncertainties, it provides limited empirical insights into how these technologies are practically implemented. Future research could adopt research designs to specifically examine the integration of specific digital tools, such as blockchain and carbon accounting platforms, in emissions management.

Fourth, while the in-depth case study approach in Publication IV provides valuable insights into sustainability in ICT service procurement, its findings are context-specific and may not be generalizable to all industries or regions. The focus on a single lead firm in the financial services sector, operating in a heavily regulated environment with significant ICT service spending, means that the challenges, drivers, and practices identified may not fully apply to other industries with different ICT spending levels, regulatory frameworks, or procurement maturity. Future research should replicate this study in sectors with less regulatory oversight or lower ICT service intensity to explore the extent to which these findings are transferable. Additionally, the sample size limits the breadth of perspectives captured. While the inclusion of global suppliers with broad customer bases mitigates this limitation to some extent, a larger sample incorporating more diverse supply chain actors could provide a more comprehensive understanding of sustainability dynamics in ICT service procurement. Finally, Publication IV focused primarily on supplier-buyer relationships and practices, offering limited insights into the long-term implementation and outcomes of these practices. Future research could adopt longitudinal designs to examine how sustainability practices in ICT service procurement evolve over time and their sustained impact on sustainability performance and supply chain resilience.

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