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Enhancing Resilience in International Supply Chains: The Role of Sustainable Development in a VUCA World

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Abstract

In today's VUCA (Volatility, Uncertainty, Complexity, Ambiguity) world, which exerts strong pressure on international and global supply chains, academia and business are actively seeking new strategies to foster their sustainable and uninterrupted development. The results of our study, using statistical methods such as analysis of variance, show that the implementation of sustainable development principles in supply chain management positively affects the resilience of supply chains to sustainability risk across the pre-disruption, during-disruption and post-disruption phases. This, however, is contingent on a process-based approach to supply chain management and a high level of managerial awareness of the various types of risks to supply chains. Furthermore, our findings confirm that the key organizational characteristics are significant determinants of this resilience. Specifically, we observed that company size, the origin of the capital, and the degree of internationalization all affect supply chain resilience across the three disruption phases. Sustainable and resilient (SUS-RES) supply chains, which employ proactive, concurrent, and reactive approaches, are particularly noticeable in the supply chains of large enterprises with foreign capital or foreign branches. This suggests that managing international supply chain sustainably can also improve their resilience.

Keywords: sustainability risk, sustainable resilience, international supply chain, process orientation, SCRES, SUS-RES supply chain, VUCA world

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Introduction

Every day, companies face challenges that test their ability to operate effectively under volatile and uncertain conditions. The international environment, which is often linked to the volatility of external factors such as economic, political, legal, social, and environmental influences, increases this uncertainty. The level of risk is also heightened by the number and nature of supplier-customer relationships, which determine the complexity of the supply chain structure. Decisions made within this network often lead to uncertain outcomes and unpredictable costs. The VUCA (volatility, uncertainty, complexity, ambiguity) world presents a challenging environment in which existing strategies, practices, and traditional thinking in businesses often prove ineffective (Sinha and Sinha 2020). Therefore, understanding the operational context and adopting a tailored approach to building supply chain resilience (SCRES) is essential (Kazancoglu et al. 2022; Hong et al. 2023).

Supply chain risk management (SCRM) has become an urgent challenge for many companies, especially in terms of sustainability risk management. Risk management in a value chain can be seen as a burden for companies, but sustainable development in supply chains can enhance their resilience. There are clear interdependencies between resilience and sustainability. Combining both areas can transform supply chain management. Therefore, researchers are investigating the relationship between sustainable development and SCRES (Jabbarzadeh, Fahimnia, and Sabouhi 2018; Negri et al. 2021). Numerous studies confirm that resilience positively impacts sustainability. For instance, Jabbarzadeh, Fahimnia, and Sabouhi (2018) found that resilience strategies can minimize expected costs and maximize overall sustainability performance during disruptions.

Although studies on the reverse relationship are less common, interest in them is growing. Sabouhi, Jabalameli, and Jabbarzadeh (2021) developed a methodology for designing a sustainable supply chain resilient to random disruptions, while Eggert and Hartmann (2023) observed the positive effects of sustainable supply chain management on readiness and recovery post-disruptions. Research on the impact of sustainability on resilience still does not sufficiently address sustainable supply chain management from a process-oriented and international perspective, nor does it consider resilience to sustainability risks before, during, and after disruptions.

Enhancing resilience in the context of sustainable development and the VUCA world is critically important in the current global context. Therefore, this article is an important contribution to the discussion on the relationships between sustainability and resilience and on the possibilities of building sustainable and resilient (SUS-RES) supply chains. The aim of this paper is to examine the impact of sustainability on international SCRES in the context of sustainability risk and three disruption phases. To achieve this objective, the paper discusses specific relationships formulated in four research hypotheses. Mainly, it analyzes whether and how the implementation of sustainability principles in supply chain processes affects SCRES to sustainability risks in three phases of disruption. Furthermore, the study considers how specific company characteristics, such as size, origin of capital, and degree of internationalization, can affect this resilience.

To verify our hypotheses, we conducted a quantitative study among manufacturing enterprises in the Polish market with a national or international supply chain. Statistical analysis led to significant conclusions, offering both theoretical and practical implications for building SUS-RES supply chains in the international context.

The article constitutes a significant contribution to the ongoing discourse for three main reasons. Firstly, sustainable development is a strategy of global importance, as emphasized by the United Nations 2030 Agenda for Sustainable Development, which defines 17 Sustainable Development Goals. This underscores the need for international enterprises to increasingly integrate sustainability aspects into supply chain management.

Secondly, legal, political, economic, and social factors – including non-financial reporting and ESG requirements – strongly drive the adoption of sustainability principles. It is essential to explore whether and how this implementation positively influences business operations and the development of resilient supply chains. Research that identifies and highlights the impact of implementing sustainability principles is crucial for building resilient and sustainable supply chains in the VUCA world. A novel aspect of this study is its focus on the impact of sustainability on SCRES, particularly before, during, and after disruptions occur.

Thirdly, the research was conducted between September 5 and 16, 2022 – a critical period for both the economy and society, as well as for the development of resilient international supply chains – shortly after the COVID-19 pandemic and the outbreak of the war in Ukraine. These events had a profound impact on the stability of supply chains, especially those of international manufacturing companies, whose operations depend on global access to resources and markets. The findings may support enterprises in making strategic decisions related to implementing sustainability to build resilient and sustainable supply chains. Existing research does not sufficiently account for the perspective of building SUS-RES supply chains across pre-, during- and post-disruption phases, specifically among manufacturing companies within the period studied.

The article comprises a theoretical and an empirical part. The first section presents the theoretical background, drawing on findings from the existing literature on SUS-RES supply chains. The subsequent sections outline the hypotheses development and the research methodology, and present and discuss the results of the study.

Theory background

Sustainable development principles in international supply chains

Sustainability principles are being implemented in business, in the context of innovation and improved stakeholder relations (Laszlo and Zhexembayeva 2011). Supply chain management models are being developed to meet competing needs, reduce Zhexembayeva negative environmental impacts, and ensure positive impacts on stakeholders and beneficiaries, which is explicitly linked to the implementation of sustainability principles. The integration of sustainability principles in supply chains is becoming increasingly common (Feng, Zhu, and Lai 2017). Supply chain

management has the potential to reduce resource consumption while sustainability principles are consistently implemented as part of business strategies (Yakovleva, Frei, and Murthy 2019).

Sustainable supply chain management has been a key area of focus due to growing environmental concerns, regulatory pressures, and stakeholder expectations (Maghsoudi et al. 2023). A sustainable supply chain strategy is defined in relation to the triple-bottom line (TBL) end result and its three elements: economic, environmental, and social (Vergara, Martínez, and Salais-Fierro 2023). It is increasingly important to create a business that is based on the principles of sustainability while remaining resilient to disruptions that occur (Bals et al. 2019). The supply chain contributes to economic development while maintaining business profitability (Dahlsrud 2008), caring for the environment, and ensuring proper ecological balance (Sufiyan et al. 2019). It also considers the relationship between business and society (Dahlsrud 2008). These dimensions are not merely theoretical; they are a consequence of growing social pressure from governments and competitors, as well as political conditions. This clearly indicates that in logistics operations, supply chain links must prioritize social and environmental impacts (Al-Swidi, Hair, and Al-Hakimi 2023).

Key areas include optimizing energy consumption, reducing emissions, ethical working practices, the principles of the circular economy, and managing stakeholder relationships throughout the value chain (Hofstetter et al. 2021). A genuine commitment to sustainable development involves adopting strategies that deliver economic, social, and environmental benefits, and responsibly using resources for future generations (Rahimi, Maghsoudi, and Shokouhyar 2024). Sustainable business models are increasingly recognized as sources of competitive advantage (Ebinger and Omondi 2020). Sustainable supply chains support resilience building and help deal with uncertainty (El Sayed and Baky 2023). The risk of disruption in supply chain networks requires considering risk and variability throughout the design of resilient systems (Lee 2022). Addressing these challenges is essential to continue developing the sustainability aspect of international supply chains. Organizations need to be proactive in this context. There is also a growing awareness among companies, indicating that sustainable business practices support effective risk management while meeting growing customer expectations (Mirzaei and Shokouhyar 2023).

Sustainable supply chain risk and resilience

Risks to the sustainable development of supply chains encompass environmental, social and economic dimensions (Xu et al. 2019). Each of the triple bottom line dimensions can be related to both exogenous and endogenous events (Giannakis and Papadopoulos 2016). The general classification of sustainable supply chain risks can also be broadened to include operational risk (Christopher and Gaudenzi 2015), institutional risk, and technical risk (Moktadir et al. 2021), or even more risk categories (Wang and Rani 2022). Regardless of the scope, the predictability of the probability and effects of environmental, social, and economic risks can vary widely, from "known knowns," for which traditional statistical models can be applied, to black swan events and "unknowable unknown" scenarios that go beyond the knowledge of managers.

Sustainability risks can disrupt information, goods and financial flows, negatively impacting internal and external supply chain stakeholders. Therefore, a comprehensive risk management process becomes a key approach for achieving supply chain sustainability (Giannakis and Papadopoulos 2016). Sustainable supply chain risk management involves identifying events that may hinder the achievement of sustainable development goals, as well as risk measurement, risk evaluation, risk treatment, risk monitoring, and control (Tundys et al. 2024, p. 96). Nowadays, cooperative risk management, particularly cultivating a risk-aware culture, is one of the most important elements of supply chains that aim to be resilient to effectively operate in the VUCA world (Hohenstein et al. 2015).

SCRES is "the supply chain's ability to be prepared for unexpected risk events, responding and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state in order to increase customer service, market share, and financial performance" (Hohenstein et al. 2015). In recent years, the interplay between sustainability and SCRES has become increasingly evident. For example, research confirms the positive impact of resilient strategies on economic and environmental sustainability (Singh, Hamid, and Garza-Reyes 2023). Likewise, sustainable development practices have also been shown to have a positive impact on SCRES (Tundys et al. 2024, pp. 137–142). Thus, building SUS-RES supply chains can yield significant benefits for companies.

Hypothesis development

Supply chain processes, sustainability risk, and supply chain resilience

The process approach to supply chain management is recognized as a best practice and is embodied in two main supply chain management reference models: the Global Supply Chain Forum (GSCF) framework (Lambert and Cooper 2000; Croxton et al. 2001) and the Supply Chain Operations Reference (SCOR) framework (APICS 2017). Research suggests that applying these models can have significant sustainable economic and environmental benefits, particularly in collaborative manufacturing networks (Siong Kuik, Verl Nagalingam, and Amer 2011).

The characteristics of the VUCA world underscore the critical need for robust and adaptable supply chain processes. Managing these processes in volatile and uncertain environments requires not only efficiency but also a proactive approach to understanding potential risks, where sustainability becomes an important framework for building more resilient supply chains (Malindretos and Binioris 2014; Negri et al. 2021; Shishodia et al. 2023). Eggert and Hartmann's (2023) detailed study confirmed that higher intensity in sustainable supply chain management increases readiness for disruptions, and that greater experience with sustainable supply chain management leads not only to increased readiness but also faster recovery after disruption.

Furthermore, the extensive literature on the subject indicates that risk management awareness and culture are important elements of building both proactive and reactive SCRES strategies (Hohenstein et al. 2015; Ali, Mahfouz, and Arisha 2017; Um and Han 2021). Some research also suggests that the risk management process is crucial for effective, sustainable supply chain management (Giannakis and Papadopoulos 2016; Wang, Cheng, and Wang 2022; Tundys et al. 2024, p. 96).

Against the background of previous research, it is valuable to see how implementing sustainable development principles in specific supply chain management processes affects SCRES, particularly in proactive, concurrent, and reactive strategies.

Therefore, the following hypothesis is proposed:

H1: Implementing the principles of sustainable development in supply chain processes affects supply chain resilience to sustainability risks in the pre-disruption, during-disruption and post-disruption phases.

Company size and supply chain resilience

Significant differences in supply chain management approaches between Small and medium-sized enterprises (SMEs) and large companies have been noted, primarily related to awareness and the feasibility of implementing similar solutions (Ramakrishna 2016). SMEs tend to focus less on planning and control methods than large companies, which may hinder their ability to address supply chain challenges (Vaaland and Heide 2007).

In the context of a VUCA world, the impact of company size on SCRES becomes even more pronounced. While large enterprises might have more resources to invest in resilience and sustainability, SMEs may have greater flexibility in adapting to external changes. As companies grow and become increasingly internationalized and global (Di Paola, Cosimato, and Vona 2023), their external environment changes and the complexity of their supply chains increases, making managing risk and uncertainties more demanding.

Research has identified differences between small, medium and large companies in areas such as risk awareness, supplier and customer relationship management, and the types of risk controls implemented (Wieteska 2011a; 2011b). For SMEs, collaboration is a key capability to deal with supply chain risk (Alzate et al. 2022). However, comparative research on supply chain management between small, medium, and large companies remains limited (Ramakrishna 2016). Thus, further analysis of these differences in relation to resilience and sustainability is warranted.

Therefore, the following hypothesis is proposed:

H2: Company size affects supply chain resilience to sustainability risks in the pre-disruption, during-disruption and post-disruption phases.

Company internationalization and supply chain resilience

The need to enhance the resilience of international supply chains is increasingly being captured in the concept of the VUCA world. A VUCA environment, which is characterized by unpredictable and rapid changes spreading to different countries, profoundly impacts global operations. Global supply chains are particularly vulnerable to the variability of a diverse international environment (Di Paola, Cosimato, and Vona 2023). However, global supply chains also offer better opportunities for effective risk management through strategies such as diversification and flexibility (Manuj and Mentzer 2008; Chu, Park, and Kremer 2020). Um and Han (2021) further observed that resilient strategies can efficiently mitigate global supply chain risks.

The challenges inherent in a VUCA world, such as geopolitical risks, climate-related events, and pandemics, require international supply chains to not only become resilient but also to proactively implement sustainability to manage multifaceted threats (Cavusgil et al. 2021; Wieland 2021). Therefore, international and global supply chains are expected to lead in implementing risk and resilience management. Thus, enterprises that are part of international corporations are often the source of best practices in SCRM (Tang, Zimmerman, and Nelson 2009).

However, following the COVID-19 pandemic, supply chain managers began to consider returning to domestic and local supply networks and manufacturing systems (Ivanov 2021). Additionally, the severity of the war in Ukraine has shown that having foreign suppliers and customers is risky, potentially disrupting the continuity of manufacturing processes and delivering products and services (Tundys et al. 2004, pp. 108–113). The consequences of such disruptions may be exacerbated by single sourcing strategies and locating suppliers in one geographical area (Norrman and Jansson 2004; Haraguchi and Lall 2015).

In light of the concerns regarding whether the supply chains of domestic or international companies achieve better resilience today, the following two hypotheses are proposed:

H3: The origin of capital affects supply chain resilience to sustainability risks in the pre-disruption, during-disruption and post-disruption phases.

H4: Internationalization affects a company's supply chain resilience to sustainability risks in the pre-disruption, during-disruption and post-disruption phases.

Methodology

To operationalize the designed approach, each of the three research areas was expressed through appropriate variables (Figure 1). The measurement of sustainable supply chain management using a process approach was developed based on supply chain business processes outlined in the GSCF model (Croxton et al. 2001). Five types of sustainable development risk, as presented by Moktadir et al. (2021), were adopted, and we followed Ali, Mahfouz, and Arisha (2017) understanding of SCRES and the SCRES framework. The framework is based on proactive, concurrent and reactive strategies that require the development of several supply chain capabilities to achieve SCRES: the ability to anticipate in the pre-disruption phase, to adapt and respond during the disruption phase, and to recover and learn in the post-disruption phase.

The study employed a proprietary questionnaire, with items developed by the authors and inspired by a review of the relevant literature. The questionnaire underwent validation through a pilot study conducted prior to the main survey, with feedback and revisions resulting from the pilot phase incorporated into the final version.

This study introduces a novel, process-oriented analytical framework that integrates sustainable supply chain management (SSCM) principles with resilience capabilities across the entire disruption lifecycle: the pre-disruption, during-disruption, and post-disruption phases. Unlike prior research that predominantly emphasizes either readiness or recovery, our approach enables

a multidimensional assessment of resilience that is rooted in the operationalization of sustainability across core supply chain processes.

The empirical design is based on a large-scale, stratified sample of 550 international and domestic manufacturing firms in Poland. It incorporates capital origin and internationalization dimensions, which remain underexplored in the extant literature. Furthermore, by aligning the GSCF process model with sustainable development risk typologies and SCRES capabilities, the study offers a unique methodological synthesis that bridges conceptual gaps between sustainability and resilience. This integrative perspective contributes to the international discourse by empirically substantiating how embedded sustainability practices condition resilience-building mechanisms in global supply chains operating under VUCA pressures.

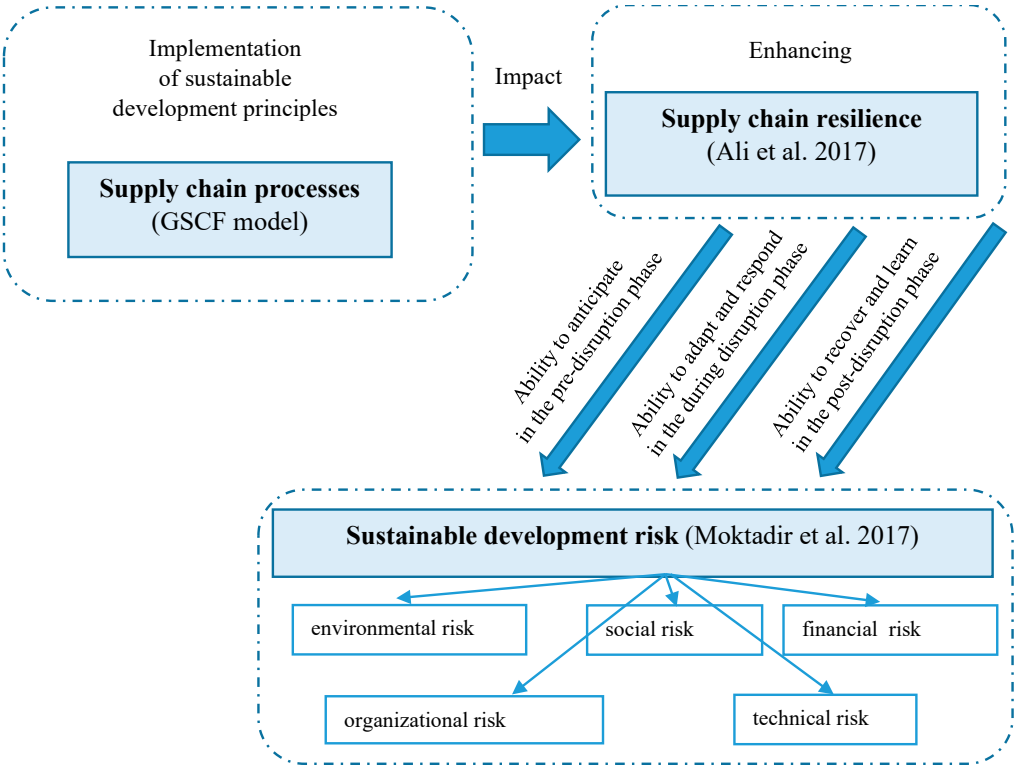

Figure 1. Research framework

Source: own study.

The survey covered 550 manufacturing companies operating in Poland, spanning a range of sizes and sectors, and active in both domestic and international markets. The ownership structure of the participating enterprises was diverse: 69% were domestically owned, 21% had foreign ownership, and 10% had mixed capital. Additionally, 32% of the companies reported having foreign branches, while 68% operated solely within Poland.

The sample was selected using a quota-based sampling method supported by purposive selection, reflecting the structural characteristics of the target population. Recruitment was conducted in collaboration with a professional research agency that maintains an extensive B2B contact database. Key eligibility criteria – including company size (more than 50 employees) and engagement in SSCM practices – were verified through a pre-screening process conducted by the agency, based on proprietary and validated internal databases. Further, emphasis was placed on ensuring

respondent competence. Only individuals holding top management positions, i.e., CEOs, board members, company owners, or managers responsible for purchasing and supply chain management, were invited to participate. Data collection was conducted using the Computer-Assisted Telephone Interviewing (CATI) method between September 5th and 16th, 2022, with operational support provided by the external research company.

The research instrument addressed all three research areas: sustainable development in supply chain processes, sustainability risk categories, and SCRES to the sustainability risk. The questionnaire was constructed so that each area was represented by statements derived from previous studies, with each statement corresponding to an observable variable measured on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). The survey was preceded by preliminary research on a small sample of companies from the relevant sector. The pilot phase aimed to assess the questionnaire's content and clarity of structure and variables. Feedback from this stage was included in the final version of the questionnaire.

Research results

The initial analysis examines how the implementation of sustainable development principles, using a process-oriented approach to supply chain management, affects SCRES to sustainability risks across the pre-disruption, during-disruption and post-disruption phases (hypothesis H1).

To assess this effect, responses from the questionnaire on the impact of implementing sustainability principles in supply chain management processes were analyzed. Responses on a 5-point Likert scale were grouped as follows: 1 and 2 (group NO), 3 (group MODERATE), 4 and 5 (group YES). For the classification of risks to sustainability, we adopted the five categories defined by Moktadir et al. (2021). In the survey, all responses for each risk were averaged to determine resilience for each of the three phases of disruption. The average Likert scale responses for each group are presented in Table 1.

Table 1. Average Likert scale response values in the pre-disruption (anticipate), during-disruption (adapt and respond), and post-disruption (recover and learn) phases, grouped by level of sustainable development implementation

		Supply chain resilience to sustainability risks		
The enterprise implements the principles of sustainable development in the process		ability to anticipate	ability to adapt and respond	ability to recover and learn
Supplier relationship management	YES	3.73	3.83	3.84
	MODERATE	2.87	3.11	3.24
	NO	2.58	3.19	3.29
Customer relationship management	YES	3.82	3.86	3.86
	MODERATE	2.97	3.19	3.25
	NO	2.54	3.22	3.41

		Supply chain resilience to sustainability risks		
The enterprise implements the principles of sustainable development in the process		ability to anticipate	ability to adapt and respond	ability to recover and learn
Customer service management	YES	3.87	3.90	3.90
	MODERATE	3.03	3.14	3.21
	NO	2.50	3.25	3.43
Demand management	YES	3.78	3.89	3.91
	MODERATE	3.00	3.27	3.37
	NO	2.65	3.04	3.11
Order fulfilment	YES	3.79	3.84	3.83
	MODERATE	3.02	3.39	3.49
	NO	2.45	2.93	3.08
Production flow management	YES	3.67	3.85	3.89
	MODERATE	3.03	3.31	3.38
	NO	2.82	2.84	2.83
Returns management	YES	3.92	3.95	3.93
	MODERATE	2.60	3.14	3.28
	NO	3.14	3.32	3.41

Source: own study.

Table 1 shows that companies that implemented sustainability in their processes (the YES group) showed greater resilience to sustainability risks in the pre-disruption, during disruption, and post-disruption phases, as evidenced by higher average response values compared to the MODERATE and NO groups.

To test whether these differences are significant, an analysis of variance (ANOVA) was conducted. ANOVA tests whether there are statistically significant differences between the means of two or more groups (Keselman et al. 1998). However, it does not provide insight into effect sizes or indicate which groups caused the differences to be significant (Murphy, Myors, and Wolach 2003). The groups analyzed are significantly different from each other if the calculated value of the F statistic is greater than the corresponding theoretical F value from the Snedecor distribution for the appropriate number of degrees of freedom at a given level of significance. The results of the ANOVA calculation are shown in Table 2.

Table 2. Results of the analysis of variance for differences between groups with varying levels of sustainable development implementation in terms of their ability to anticipate sustainability risk, adapt and respond, and recover and learn

The enterprise implements the principles of sustainable development in the process	Supply chain resilience to sustainability risks	F	*p*-value
Supplier relationship management	ability to anticipate	81.03794	0.000000
	ability to adapt and respond	51.68529	0.000000
	ability to recover and learn	34.25919	0.000000
Customer relationship management	ability to anticipate	111.1931	0.000000
	ability to adapt and respond	50.9276	0.000000
	ability to recover and learn	33.7942	0.000000
Customer service management	ability to anticipate	134.1918	0.000000
	ability to adapt and respond	63.0524	0.000000
	ability to recover and learn	41.4162	0.000000
Demand management	ability to anticipate	75.00932	0.000000
	ability to adapt and respond	60.44688	0.000000
	ability to recover and learn	48.06144	0.000000
Order fulfilment	ability to anticipate	92.69357	0.000000
	ability to adapt and respond	49.19146	0.000000
	ability to recover and learn	30.75715	0.000000
Production flow management	ability to anticipate	37.68646	0.000000
	ability to adapt and respond	56.23200	0.000000
	ability to recover and learn	55.67761	0.000000
Returns management	ability to anticipate	121.8485	0.000000
	ability to adapt and respond	65.5251	0.000000
	ability to recover and learn	39.3853	0.000000

Source: own study.

Table 2 shows that the F-value is higher than the theoretical value of the test for all the groups studied, while the *p*-value is low (less than 0.05) in each case. This indicates that there are statistically significant differences between companies that implement sustainability in particular processes in their ability to anticipate, adapt and respond, and recover and learn. Thus, hypothesis H1 has been positively verified.

When considered alongside the average results presented in Table 1, it can be concluded that companies with a higher degree of sustainability implementation are capable of managing sustainability risks in the pre-, during- and post-disruption phases. Additionally, Table 2 reveals that, in most cases, the implementation of sustainability principles has the greatest impact on risk anticipation, as indicated by the highest *F* values.

In-depth analyses were conducted to examine the characteristics of the surveyed companies, such as the number of employees, origin of capital, and ownership of foreign affiliates (hypotheses H2–H4). The analyses explored the differences among groups in their ability to anticipate sustainability risks, adapt and respond, and to recover and learn in the post-disruption phase. The average response results for each group are presented in Table 3.

Table 3. Average Likert scale response values in the pre-disruption (anticipate), during-disruption (adapt and respond), and post-disruption (recover and learn) phases by enterprise characteristics

		Supply chain resilience to sustainability risks		
Feature		Ability to anticipate	Ability to adapt and respond	Ability to recover and learn
Number of employees	51–250	3.27	3.47	3.52
	251–500	3.50	3.73	3.78
	over 500	3.66	3.80	3.84
Origin of capital	domestic and foreign	3.32	3.52	3.56
	domestic	3.30	3.49	3.55
	foreign	4.05	4.35	4.34
Ownership of foreign affiliates	Yes	3.52	3.78	3.81
	No	3.32	3.49	3.55

Source: own study.

Table 3 indicates that a company's internationalization influences its resilience to sustainability risks. Specifically, companies with foreign capital, as well as those with foreign affiliates, report higher average responses across all disruption phases compared to companies with domestic or mixed capital. The number of employees also affects SCRES to sustainability risks, with the largest companies demonstrating higher average responses in all three categories. These relationships are further illustrated in the graphs presented in Figure 2, which included 95% confidence intervals.

To confirm the significance of this impact, an analysis of variance was performed. The results are presented in Table 4.

Table 4 shows that, for all groups examined, the F value is higher than the theoretical value of the test, with a low p-value (below 0.05), indicating statistically significant differences between companies in terms of company size, origin of capital, and ownership of foreign affiliates. These findings statistically confirm the results in Table 3 and Figure 2, which highlighted differences in the surveyed companies according to these characteristics. Thus, hypotheses H2, H3 and H4 have been positively verified.

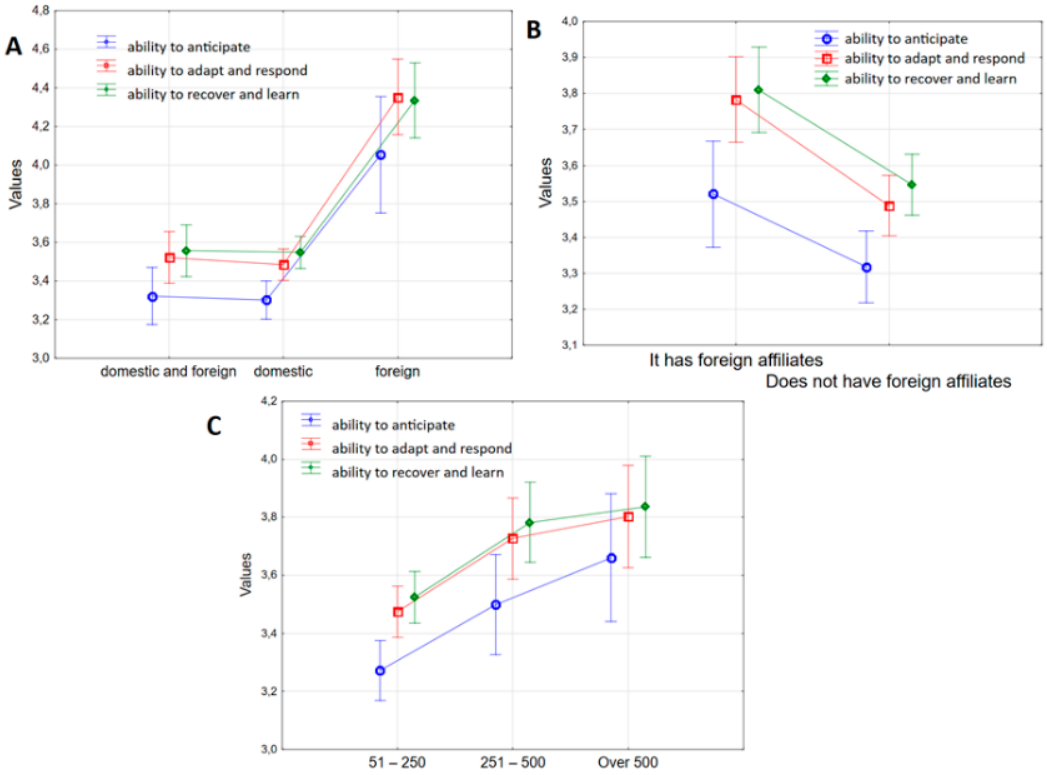

Figure 2. Mean values and 95% confidence intervals for responses in the pre-disruption (anticipate), during-disruption (adapt and respond), and post-disruption (recover and learn) phases by (A) origin of capital, (B) ownership of foreign affiliates, and (C) number of employees.

Source: own study in Statistica software (Statsoft v.13).

Table 4. Results of the analysis of variance examining differences in company size and internationalization on the ability to anticipate sustainability risk, adapt and respond, and recover and learn

Feature	Supply chain resilience to sustainability risks	*F*	*p*-value	Verification of the hypothesis
Number of employees	ability to anticipate	6.427 104	0.001 742	H2 positive
	ability to adapt and respond	7.973 873	0.000 386	
	ability to recover and learn	7.587 000	0.000 562	
Origin of capital	ability to anticipate	15.22 130	0.000 000	H3 positive
	ability to adapt and respond	30.18 192	0.000 000	
	ability to recover and learn	24.27 710	0.000 000	
Ownership of foreign affiliates	ability to anticipate	5.02 982	0.025 313	H4 positive
	ability to adapt and respond	15.60 007	0.000 088	
	ability to recover and learn	12.21 267	0.000 513	

Source: own study using Statistica software (Statsoft v.13).

Discussion

The research results show that implementing sustainability principles enables companies to demonstrate a greater ability to proactively anticipate, adapt to and address crises, and become more resilient to the sustainability risk in the phases before, during and after disruption. This confirmation of H1 aligns with the growing body of literature that underscores the general relationship between sustainability and SCRES (Malindretos and Binioris 2014; Negri et al. 2021; Shishodia et al. 2023).

In line with earlier findings (Shabbir et al. 2021), overlooking the risk of supply chain disruption can result in planning and actions that lack resilience and the ability to deal effectively with disruption, posing a significant risk to the overall supply chain sustainability strategy. Additionally, resilience can be compromised when companies fail to effectively manage supply chain disruptions (Queiroz et al. 2024), which can, in turn, impact the organization's performance. The literature underscores that the connection between resilience and sustainability is essential for long-term success (Ewuga and Adesi 2023; Abdelaziz, Chen, and Dey 2024). This suggests that knowledge and the effective implementation of sustainability principles may be a critical success factor in today's dynamically changing economic environment.

Risk management awareness and a strong organizational culture are crucial for building resilience strategies in the VUCA world (Hohenstein et al. 2015; Ali, Mahfouz, and Arisha 2017; Um and Han 2021). Our findings suggest that integrating sustainability principles into supply chain management fosters such an environment. In stable environments, sustainability measures, such as energy efficiency, resource recycling and environmental management, can help shape and prepare organizations for internal change (Lin and Fan 2024).

However, businesses are increasingly operating in dynamic environments where complex and unforeseen situations, such as sudden changes in environmental pressures, unexpected disruptions to the global supply chain, or changes in market demand (Ekanayake, Shen, and Kumaraswamy 2023), are more likely to arise, requiring appropriate responses. Responding dynamically and effectively to such situations requires stronger resilience and the ability to anticipate, adapt, respond, recover and learn. This can be done by building resilience through practices such as diversifying suppliers, increasing redundancy capacity, and adopting flexible logistics solutions (Silva, Pereira, and Hendry 2023; Li et al. 2025).

Our findings also show that a higher degree of implementation of sustainability principles correlates with greater resilience to sustainability risks for each disruption phase. This finding is particularly significant as it extends the observations of Eggert and Hartmann (2023), who confirmed that greater experience with SSCM translates into faster recovery. While they also noted that greater experience with SSCM translates into faster recovery, our study also demonstrates a comprehensive impact across all disruption phases directly linked to the degree of sustainability implementation. This suggests that the risk management process, deemed crucial for effective SSCM by Giannakis and Papadopoulos (2016), Wang, Cheng, and Wang (2022), and Tundys et al. (2024), is indeed enhanced by sustainability, leading to more robust resilience across the entire disruption lifecycle.

This contrasts with Eggert and Hartmann (2023), who found that the impact of sustainable supply chain management intensity mainly affects readiness, not recovery after disruption.

Sustainability practices in the supply chain aim to minimize negative environmental impacts, improve social conditions and ensure economic efficiency in delivering products and services. These practices include reducing packaging, using recyclable materials, adopting composting, and investing in renewable energy, which limit the need for new resources within the supply chain or allow consumers to upgrade or dispose of products responsibly. In supply management, this extends to sustainable supplier selection (Cui, Wu, and Dai 2023), reducing carbon footprints (Dubisz, Golinska-Dawson, and Kolinski 2023), and minimizing logistics waste (Roozkhosh et al. 2024). Equally important are the use of renewable raw materials, the implementation of a closed-loop economy, and the use of renewable energy sources.

Social responsibility (Zhang et al. 2018) refers to fair labor practices, transparency, and supporting local communities. Technological advances and digitalization, such as blockchain, RFID, and other technologies, also contribute to process optimization and sustainability, allowing tracking and transparency in the chain. Sustainability practices also include obtaining environmental certification and upholding ethical standards (Bubicz, Barbosa-Póvoa, and Carvalho 2019; Zimon, Tyan, and Sroufe 2020; Khan et al. 2021; Abualigah et al. 2023; Nikseresht, Golmohammadi, and Zandieh 2024).

The research also revealed statistical differences between companies that implement sustainability principles in individual processes and their ability to anticipate, adapt and respond, and recover and learn in the different phases of risk analysis. Our findings support the notion that a process-oriented approach to supply chain management (Lambert and Cooper 2000) provides a solid foundation. Specifically, embedding sustainability within these specific processes, as advocated by Siong Kuik, Verl Nagalingam, and Amer (2011) for collaborative manufacturing networks, indeed translates into tangible resilience benefits, particularly in risk prediction in a VUCA world. The results clearly show that implementing sustainability principles has the greatest impact on risk prediction.

Numerous practical examples and cases in the literature have highlighted poor sustainability in SCRM (Reshad et al. 2023). This has increased the pressure on companies to manage and measure social and environmental issues more effectively. Activities of this type influence the performance of supply chain processes positively or negatively (Kumar and Garg 2017). Risks are associated with unforeseen events that may have negative consequences (Hajmohammad and Vachon 2016), and sustainable supply chain risks can significantly affect organizations' sustainability principles (Zarbakhshnia et al. 2023). This situation consequently creates both challenges and opportunities to be sustainable. Therefore, it is crucial to mitigate risks that may impact individual supply chain processes, such as supply disruptions, delivery delays, price and demand fluctuations, exchange rate volatility, as well as mitigate systemic risks such as information infrastructure failures, forecasting risks due to inaccuracies, procurement and inventory risks, capacity constraints, and intellectual property risks (Chopra and Sodhi 2004; Reshad et al. 2023).

The confirmation of H2, indicating that company size affects SCRES to sustainability risks, is consistent with the existing literature. Additionally, our analysis of internationalization and capital

origin (H2 and H4) shows that companies with foreign capital are more effective at managing risks related to sustainable development. Companies with a significant proportion of foreign capital respond better to risk, with significant differences when comparing large companies with the smallest companies in the sample. This complements the results of both Vaaland and Heide (2007) and Ramakrishna (2016), who noted significant differences in awareness and feasibility of implementing SCM solutions between SMEs and large companies. It also confirms Vaaland and Heide's (2007) findings that SMEs are less focused on planning and control methods. Our results further align with Wieteska (2011a; 2011b), who identified differences in risk perception and control types based on company size. The results reveal that large companies are better at coping with supply chain challenges, such as building resilience to risks for sustainable development in the VUCA world.

A major limitation of this study is the focus on medium-sized and large companies. The exclusion of small enterprises means that insights into their unique characteristics, such as a potential reliance on collaboration to manage supply chain risk (Alzate et al. 2022), are missing from the analysis. Our study reveals that companies with foreign capital and greater internationalization manage risks and implement sustainability principles better than those with only Polish capital and a domestic focus. This aligns with the expectation that multinational corporations are often sources of best practices in SCRM (Tang, Zimmerman and Nelson 2009) and may have better opportunities for effective risk management through strategies like diversification and flexibility (Manuj and Mntzer 2008; Chu, Park, and Kremer 2020). Um and Han (2021) also observed that resilient strategies can effectively mitigate risk in global supply chains.

It is therefore necessary to consider how organizational size and capital structure influence performance, especially given that medium-sized companies respond differently to risk compared to large companies. There is no doubt that large, often multinational companies with foreign capital face greater exposure to the pressures of a VUCA world (Cavusgil et al. 2021) and the inherent vulnerabilities of global supply chains (Di Paola, Cosimato, and Vona 2023). This exposure may stem from factors like single sourcing, geographic concentration of suppliers (Norrman and Jansson 2004; Haraguchi and Lall 2015), or geopolitical events like the war in Ukraine (Tundys et al. 2024, pp. 108–113). Nevertheless, these companies typically possess the skills and resources necessary to develop better mechanisms for guaranteeing resilience (Garrido-Moreno, Martín-Rojas, and García-Morales 2024).

In summary, the research clearly indicates that companies with foreign capital and greater internationalization demonstrate greater resilience to sustainability risks. The prerequisite for this resilience, as our study confirms, is the integration of sustainability principles into supply chain processes.

Conclusions

This study contributes to the discourse on sustainable development and supply chain resilience by addressing key gaps identified in systematic literature reviews. By exploring three disruption phases and five sustainability risk categories, it demonstrates how a process-oriented approach to supply chain management strengthens resilience through proactive, concurrent, and reactive

strategies. This theoretical contribution highlights the positive impact of sustainability principles on effective risk management.

A comparative analysis of national and international supply chains reveals that large and internationalized companies are more resilient to sustainability risks across all disruption phases, suggesting that they can serve as a source of best practices. The research also underscores the need for smaller enterprises, which face financial challenges such as rising energy and raw material costs, to adopt resilience-enhancing practices. This is especially relevant in Poland, where SMEs constitute 99.8% of businesses but often lack the resources to match the resilience of larger or foreign-owned companies. The findings encourage internationally active firms and global supply chain participants to adopt sustainable principles across their processes. Simultaneously, they urge Polish companies to investigate why their resilience levels differ from those of mixed or foreign-capital companies.

Despite its contributions, the study has limitations, primarily its focus on a specific geographic context and organizational size – areas that future research should expand upon. Incorporating details on supply chain partners, raw material suppliers, and end customers would provide a deeper understanding of international dynamics. Further research should also distinguish between local and global supply chains, identify best practices for sustainable and resilient supply chains across industries and maturity levels, and incorporate emerging areas like artificial intelligence and ESG risk reporting. These efforts would help bridge gaps in the field and offer actionable strategies for enhancing SCRES in a rapidly globalizing and sustainability-focused world.

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Wzmacnianie odporności międzynarodowych łańcuchów dostaw: rola zrównoważonego rozwoju w świecie VUCA

W dzisiejszym świecie VUCA (*Volatility* – zmienność, *Uncertainty* – niepewność, *Complexity* – złożoność, *Ambiguity* – niejednoznaczność), wywierającym silną presję na międzynarodowe i globalne łańcuchy dostaw, świat nauki i biznesu intensywnie poszukuje nowych szans, które pozwolą na ich trwały i niezakłócony rozwój. Wyniki przedstawionego badania, w którym autorzy wykorzystali metody statystyczne, m.in. analizę wariancji, pokazują, że implementacja zasad zrównoważonego rozwoju w zarządzanie łańcuchem dostaw może przełożyć się na kluczowe zdolności odpornego łańcucha dostaw. Jest to możliwe w warunkach procesowego podejścia do zarządzania łańcuchem dostaw oraz świadomości menedżerów co do występowania różnych rodzajów ryzyka dla łańcuchów dostaw. Dodatkowo zrównoważone i odporne (*sustainable and resilient* – SUS-RES) łańcuchy dostaw, wykorzystujące proaktywną, równoległą i reaktywną optykę, zostały zaobserwowane szczególnie w przypadku łańcuchów dostaw przedsiębiorstw dużych, z kapitałem zagranicznym oraz z zagranicznymi oddziałami. Oznacza to, że zarządzanie międzynarodowymi łańcuchami dostaw w podejściu zrównoważonym stanowić może jednocześnie szansę na wzmacnianie ich odporności.

Słowa kluczowe: ryzyko dla zrównoważonego rozwoju, zrównoważona odporność, międzynarodowy łańcuch dostaw, orientacja procesowa, SCRES, łańcuch dostaw SUS-RES, świat VUCA