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Sustainable supply chains in the heavy vehicle and equipment industry: a multiple-case study of four manufacturers

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Abstract

Purpose – Recently, interest in sustainability has grown globally in the heavy vehicle and equipment industry (HVEI). However, this industry's complexity poses a challenge to the implementation of generic sustainable supply chain management (SSCM) practices. This study aims to identify SSCM's barriers, practices and performance (BPP) indicators in the HVEI context.

Design/methodology/approach – The results are derived from case studies of four multinational manufacturers. Within-case and cross-case analyses were conducted to categorise the SSCM BPP indicators that are unique to HVEI supply chains.

Findings – This study's analysis revealed that supply chain cost implications and a deficient information flow between focal firms and supply chain partners are the key barriers to SSCM in the HVEI. This analysis also revealed a set of policies, programmes and procedures that manufacturers have adopted to address SSCM barriers. The most common SSCM performance indicators included eco-portfolio sales to assess economic performance, health and safety indicators for social sustainability and carbon- and energy-related measures for environmental sustainability.

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Practical implications – The insights can help HVEI firms understand and overcome the typical SSCM barriers in their industry and develop, deploy and optimise their SSCM strategies and practices. Managers can use this knowledge to identify appropriate mechanisms with which to accelerate their transition into a sustainable business and effectively measure performance outcomes.
Originality/value – The extant SSCM literature has focused on the light vehicle industry, and it has lacked a concrete examination of HVEI supply chains' sustainability BPP. This study develops a framework that simultaneously analyses SSCM BPP in the HVEI.

Keywords Sustainability, Supply chain, Heavy vehicle and equipment, Barriers, Practices, Performance
Paper type Research paper

1. Introduction

The sustainability concept has gained attention due to increased social and environmental problems, such as climate change. Manufacturing and service organisations have recognised the value of adopting environment-friendly management systems to overcome sustainability challenges (Krause *et al.*, 2009). The focal companies that typically govern supply chains are pressured by stakeholders, such as non-governmental organisations (Carter and Jennings, 2002), to take responsibility for their entire supply chains' sustainability (Seuring and Muller, 2008; Colicchia *et al.*, 2011; Gimenez and Tachizawa, 2012). Firms face increased pressure to integrate the triple bottom line of sustainability in their supply chains, which has increased attention to the concept of sustainable supply chain management (SSCM) (Alinaghian *et al.*, 2020; Silva *et al.*, 2022). *SSCM* can be defined as the management and coordination of materials, information and capital flows in a way that fulfils stakeholders' and customers' economic, environmental and social goals (Shekarian, 2020; Shekarian *et al.*, 2022).

Embedding sustainability in supply chains can provide a competitive advantage. Adopting sustainable practices benefits an organisation since they can enhance brand image, increase economic performance and improve efficiency, as well as the preferential local community. In other words, the effective implementation of SSCM can lead an organisation to meet environmental and social standards (Narayanan *et al.*, 2019). SSCM's further advantages include enhanced risk management, augmented efficiencies, new business ventures for sustainability and corporate initiatives for SSCM (Sivakumar *et al.*, 2012). For organisations, SSCM's outcome is usually the achievement of market and financial targets. The nature and scope of SSCM practices have been studied in various industrial sectors (Ageron *et al.*, 2012), such as fast fashion (Turker and Altuntas, 2014), logistics (Stekelorum *et al.*, 2021), food and automobiles (Siems *et al.*, 2021) and services (Nagariya *et al.*, 2022).

The heavy vehicle and equipment industry (HVEI) includes special vehicles for heavy-duty and off-road (HDOR) use, such as mining and industrial equipment, as well as cargo lifting, loading and transportation equipment. In this industry, many manufacturers and suppliers strive to reduce costs by achieving economies of scale in production volumes and sales; arguably, however, products still consume enormous amounts of energy during production and usage. Furthermore, the HVEI faces such challenges as virgin materials' price volatility and scarcity, which require manufacturing organisations to implement sustainable practices. Sustainability is key since it can make the HVEI more efficient and effective. Heavy vehicles and equipment significantly contribute to environmental pollution, specifically greenhouse gas emissions, that can be reduced by promoting sustainability. Sustainable heavy vehicles can be designed to use fewer resources, including energy, which leads to economic benefits. Consumers are also increasingly conscious of environmental and social issues and more likely to support businesses that prioritise sustainability. Moreover, the strong leverage of regulatory compliance should not be forgotten, as ignoring it can lead to fines and legal issues.

Although the literature has somewhat addressed sustainability in similar industries, such as the light vehicle and automotive sectors, a gap concerning the HVEI persists and must be filled. Consequently, both the analysis of barriers that hinder the acceleration of SSCM performance in distinct industrial settings and the identification of related practices are crucial. Organisations must clearly understand such critical barriers to redefine and refine their connections with supply chain partners (Gopal and Thakkar, 2016). By recognising these barriers' effects, companies can equip themselves to overcome different internal and external barriers (Baig *et al.*, 2020). Furthermore, adopting sustainable practices may entail detrimental cost impacts in a highly competitive industry, particularly at the initial stage (Turker and Altuntas, 2014). Therefore, sufficiently understanding methods and avoiding any risks associated with sustainability's triple bottom lines (economic, environmental and societal) improve overall sustainability performance (Beske-Janssen *et al.*, 2015).

For companies, increasing their sustainability performance without an in-depth investigation of barriers and full comprehension of diverse collaborative strategies with which to practise sustainability is difficult. The current study's main goal was to identify SSCM barriers, practices and performance (BPP) indicators in the HVEI. A qualitative research approach and multiple-case-study methods were used to identify the SSCM BPP indicators at four case companies. This research answers the following research questions (RQs):

RQ1. What barriers hinder the HVEI's sustainability?

RQ2. What solutions can make the HVEI sustainable?

RQ3. How can the HVEI's sustainability be measured?

The scientific literature was analysed systematically to identify the generic BPP indicators for sustainable supply chains in order to provide a basis for this project's empirical study. The empirical study employed a qualitative research approach and multiple-case-study method to determine SSCM's BPP indicators at four case organisations. Although sustainability has been investigated in different industries, the present research is among the first to study sustainability in the HVEI. Its framework simultaneously includes three BPP indicators to analyse the HVEI's sustainability in developed countries.

This article is organised into six sections. In the next section, the literature is briefly presented. Section 3 explains the study's research methodology. The results are described in Section 4, and the main findings are discussed in Section 5. Finally, the conclusions are presented in Section 6.

2. Literature background

2.1 SSCM in heavy vehicle and equipment industry

Since Pagell and Shevchenko (2014) argued that researchers' knowledge is insufficient to create genuinely sustainable supply chains, this field has witnessed a significant jump in different industries (Saha *et al.*, 2022). Considering the three pillars of sustainable development (i.e. environmental, economic and social), experimental studies have investigated the sustainability of supply chain management from three perspectives: identifying barriers, proposing solutions and measuring performance (Ashby *et al.*, 2012; Golicic and Smith, 2013; Sajjad *et al.*, 2015; Dubey *et al.*, 2017; Kouhizadeh *et al.*, 2021; Khan *et al.*, 2017). These concepts have usually been investigated separately for specific industries in regions (Delmonico *et al.*, 2018; Martinho and Mourão, 2020; Shahriar *et al.*, 2022). In sectors relevant to the current study's scope, such as the light vehicle and automotive sectors, the literature is rather extensive. Due to ever-increasing environmental concerns in emerging economies, many studies have been conducted in China and India. For instance, Al Zaabi *et al.* (2013), Gopal and Thakkar (2016) and Mathivathanan *et al.* (2018) determined the inter-influences of SSCM barriers and practices with a detailed look at the automobile industry in India. Recently, the barriers to flexibility in Indian automobile supply chains have been examined from a sustainability perspective (Chirra *et al.*, 2021). Fraser *et al.* (2020) investigated the automotive industry's supply chain transparency in a multi-tier SSCM. In the present study's industrial scope – that is, a focus on the HVEI – only a few studies have investigated circular-economy and sustainability concerns.

The results of one of the earliest empirical studies on the heavy vehicles industry in Sweden and China showed that the lifecycle solution is an efficient path to SSCM, and environment and traffic safety can help tackle challenges and ease SSCM conflicts (Pereseina *et al.*, 2014). Pereseina *et al.* (2014) showed that firms perceived challenges at the regulatory and organisational levels. Concerning the dearth of research on HDOR vehicles' end-of-life (EoL) stage in the literature, Saidani *et al.* (2018a) discussed the extension of the circular economy through an extensive literature survey and in-depth investigations. They studied the industrial practices and regulations of automotive and HDOR industries in the European Union; later, the study was extended to analyse the HDOR circular economy in the United States (Saidani *et al.*, 2018b). Saidani *et al.* (2019) analysed the possible transfer and applications of the best managerial practices, regulations and know-how from the automotive sector to the heavy vehicle sector, which share some similarities (e.g. components and materials) but are also distinct (e.g. in terms of regulations and marketing practices). In this line, a practical benchmarking template was developed and disseminated to key industrial players in the heavy vehicle industry (Talapatra and Uddin, 2019). Talapatra and Uddin (2019) concluded that, while the European Union appears to be a few steps ahead in its policy activity regarding the management of EoL automotive vehicles (Directive 2000/53/ EC), the US heavy vehicle industry presents several aspirational industrial practices – including collaboration between EoL actors – supporting parts remanufacturing and facilitating reuse. Naumanen *et al.* (2019) investigated the development of heavy-duty electric battery vehicles and identified emerging technology areas through a more detailed examination of China, Europe, Japan and the United States. In cooperation with an international remanufacturing centre of heavy handling machines in France, Saidani *et al.* (2020) illustrated factors that arise when closing the loop on heavy vehicles, namely technical and organisational knowledge and economic considerations. They considered the entire EoL management of a whole heavy vehicle, from dismantling to the recovery of used parts through remanufacturing. Recently, Rönkkö *et al.* (2021) studied the advantages (and disadvantages) of the regional remanufacturing operations of a Finnish heavy vehicle manufacturer that operated globally. Clearly, the number of studies in this field is limited, and only a few researchers are active in the scientific literature. The present study contributes to the literature by considering the three main streams simultaneously. Particularly, it clarifies the SSCM situation for the HVEI in developed countries by addressing issues discussed with the experts in this field.

2.2 Barriers, practices and performance in SSCM

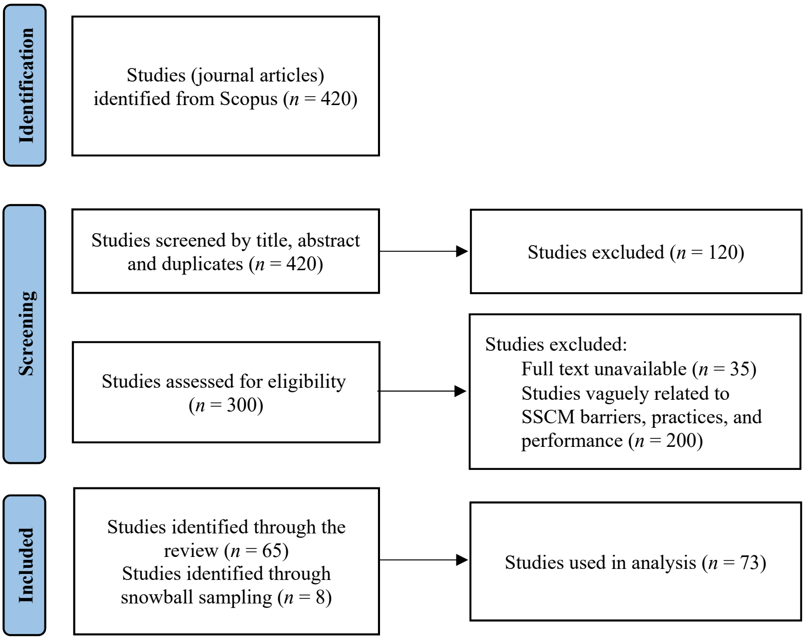
To achieve this study's objectives, the scientific literature on SSCM was first scrutinised using a systematic literature review (Tranfield *et al.*, 2003) to point out existing factors in target sections (i.e. BPP). In this approach, Scopus was used as the main database, and searches of journal papers in English were conducted separately for each section. A combination of the main keywords 'supply chain management', 'sustainable supply chain' and 'sustainability', with relevant keywords in each section, were searched for, as follows:

(1) Barriers: 'obstacle', 'hinder', 'barrier', 'challenge' and 'pressure'

(2) Practices: 'practice', 'solution', 'enabler', 'adaptation', 'implementation' and 'execute'

(3) Performance: 'indicators', 'measures' and 'metrics'

The initial search yielded 420 published studies. After screening the abstracts and titles and removing duplicated sources, 300 studies – including review papers and original research articles – were selected. The content of the selected studies was examined, considering the application of sustainable supply chains. We collected 65 articles. Snowball sampling of these studies' references added eight more papers, finally resulting in 73 articles. Figure 1 shows the literature review protocol. The content of the derived references was analysed to categorise the factors in each section. Table 1 represents the results pertaining to the three sections (A, B and C).



Source(s): Authors own work

Figure 1. Literature review protocol (adapted from the preferred reporting items for systematic review or PRISMA)

3. Method and data

Given the study's exploratory and descriptive nature, a qualitative method was considered the most suitable approach (Voss *et al.*, 2002). The multiple-case method is a qualitative research approach that is well-suited to examining complex structures, such as supply chains, since it facilitates intensive interaction with informants and draws on multiple sources of information, resulting in robust data (Eisenhardt, 1989; Yin, 2014). It was also considered an appropriate method, owing to the complexity of HVEI supply chains. Following the guidelines by Barratt *et al.* (2011), we adopted a four-step process to conduct case studies: (i) selecting cases and interviewees; (ii) conducting interviews and analysing the content; (iii) collecting secondary data; and (iv) performing within-case and cross-case analysis and deriving conclusions.

3.1 Case and interviewee selection

Selection criteria were established to ensure that the studied cases were relevant and representative. Because practical insights were sought and SSCM is especially relevant to HVEI manufacturers, we tried to identify suitable firms. Large and industry-leading companies tend to possess more resources and skilled labour than smaller ones, so manufacturers with more than 1,000 employees were searched for. The companies were also required to be focal companies in their supply chains, to rank sustainability high on their agendas or to increasingly invest in developing sustainability. Interviewee selection required informants from mid- or senior-level management, extensive industry experience (lasting over 15 years) and sustainability-related responsibilities. Both supply chain and sustainability experts and managers were sought since sustainability work is typically divided between sustainability and supply chain teams at companies. This approach also aimed to provide a holistic understanding of the studied phenomena. Final interviewee selections were made in collaboration with companies. Accordingly, four global, industry-leading manufacturers that were headquartered in Nordic

Category	Description	References
SSCM barriers		
Flow of information	No proper channels for the correct information, unwillingness to share information about used technologies and implemented changes among organisations, lack of collaboration	Al Zaabi *et al.* (2013), Delmonico *et al.* (2018), Caldera *et al.* (2019), Nazam *et al.* (2020)
Financial and economic	Lack of sufficient financial sources or intention to invest, low priority to fund sustainability and a high cost of implementing sustainability	Delmonico *et al.* (2018), Kathirve *et al.* (2019), Sirilertsuwan *et al.* (2019), Jia *et al.* (2020), Narimissa *et al.* (2020)
Technological capabilities	Resistance to change, intention to maintain traditional practices, immature technology or the absence of innovation, difficulties in designing and developing a durable product	Gupta and Barua (2018), Gupta *et al.* (2020)
Upper-level management	Lack of managers' support for providing resources and facilities to adopt sustainable practices	Movahedipour *et al.* (2017), Zayed and Yaseen (2020)
Human resources	Absence of human capital to improve the company's efficiency, train a system or improve know-how in a system	Caldera *et al.* (2019), Baig *et al.* (2020), Jalilian and Mirghafoori (2020)
Government	Inadequate legislation and regulations, less emphasis on environmental aspects or inadequate incentives to support SSCM implementation	Sajjad *et al.* (2020), Zayed and Yaseen (2020)
Customers	Consumers' unwillingness to use sustainable products	Kathirve *et al.* (2019), Sirilertsuwan *et al.* (2019)
SSCM practices		
Programmes and supportive plans	Tools, projects, and activities employed internally and externally to achieve sustainability	Morali and Searcy (2013), Jia *et al.* (2015), Qorri *et al.* (2021)
Supply chain management operations	Improving different operations through the company's supply chain	Gimenez and Tachizawa (2012), Cousins *et al.* (2019), Alinaghian *et al.* (2020)
Product and services	Developing produced items and services sustainably	Ashby *et al.* (2012), Beske-Janssen *et al.* (2014), Broemer *et al.* (2019)
Data analytics and information	Enhancing data application to increase sustainability	Das (2018), Laosirihongthong *et al.* (2020)
Social and environmental practices	Activities for the community and environment surrounding the company	Marshall *et al.* (2015), Köksal *et al.* (2017), Croom *et al.* (2018)
Specific and innovative practices	The company's specific contributions and inventions to create a sustainable system	Raut *et al.* (2017), Kumar *et al.* (2020), Nilsson and Göransson (2021)
SSCM performance		
Financial or economic performance	Expected financial benefits resulting from SSCM practices	Govindan *et al.* (2014)
Operational performance	Improvements in operational activities to more efficiently produce and deliver products to customers	Zhu *et al.* (2005), Mitra and Datta (2014)
Ecological or environmental performance	SSCM practices' impact on the natural environment within and beyond organisations	Fahimnia *et al.* (2015)
Social performance	Improvements in stakeholder welfare, community health and workers' safety	Beske-Janssen *et al.* (2015)

Source(s): Authors own work

Table 1.
SSCM's BPP indicators

countries were selected. Eight interviews were conducted. Table 2 describes the selected companies and interviewees.

3.2 Interviews, content analysis and information triangulation

Online interviews were conducted in 2021. Interviewees and participating companies were anonymised to ensure rich, high-quality responses. The interviews were semi-structured, which enabled not only focused discussions but also open answers. Part 1 of the study's data collection comprised the interviews and understanding companies' backgrounds. The second section focused on SSCM practices, the third section on SSCM performance indicators and the fourth section on SSCM barriers. The protocol for the interviews, along with the questions investigated in each section and the instructions, are presented in Appendix.

The interviews lasted between 46 and 86 min. They were conducted by four to six researchers to increase the data's reliability. The interviews were recorded and transcribed, and the transcripts were sent to the informants for verification. The interview transcripts were analysed using the qualitative content analysis (QCA) procedure recommended by Schreier (2012). QCA is a flexible, systematic data reduction process to analyse data within limits defined by a research question. First, a coding frame was created using the MAXQDA-11 qualitative data analysis software. The SSCM's BPP parameters (Table 1) were used as the main categories (Kovács and Spens, 2005). Then, we followed the QCA procedure to create sub-categories by reading and checking the interview transcripts.

The interview data were later coded into identified categories. The coding categories for the SSCM barriers were defined as *internal* (i.e. deterrents to SSCM within an organisation) and *external* (i.e. outside inhibitors to SSCM deployments). For the SSCM practices, the coding categories were defined as (i) *policy* (i.e. overarching tenets to guide SSCM-related decision-making); (ii) *programmes* (i.e. initiatives to deal with sustainability-related challenges or achieve improvements) and (iii) *procedure* (i.e. a detailed description of actions to achieve desired sustainability outcomes). The coding categories for SSCM performance were determined as the *climate or environment performance*, *social performance* and *economic performance* outcomes of SSCM. Ultimately, data were analysed based on their frequency in interviewee quotes (marked or coded as segments in MAXQDA), according to the researchers' interpretation of each interviewee's explanation of a specific dimension. The study's two-step analysis involved, first, deductively analysing the interview quotes on SSCM's BPP and, second, inductively analysing cross-case

Company	Products	Employees	Informants	Role	Experience (years)
A	Cargo handling equipment, services	>10,000	INA.1	Sourcing director	16
			INA.2	Sustainability development manager	20
B	Lifting equipment, services	>15,000	INB.1	Director of operations	23
			INB.2	Social responsibility manager	18
C	Mining vehicles, equipment, services	>1,000	INC.1	Vice president of sourcing	25
			INC.2	Global head of Health, Safety, Environment and Quality	25
D	Equipment, vehicles, production, and mining solutions	>30,000	IND.3	Sustainability and compliance lead	18
			IND.4	Head of sustainability	20

Source(s): Authors own work

Table 2. A profile of case companies and interviewees

patterns (Eisenhardt, 1989). Based on a case-weighted frequency of quotes, the evidence for SSCM's BPP was rated as *high* (above the 80th percentile of the case-weighted frequency of quotes), *medium* (between the 50th and 80th percentiles) and *low* (below the 50th percentile). Figure 2 shows the QCA steps used in this study.

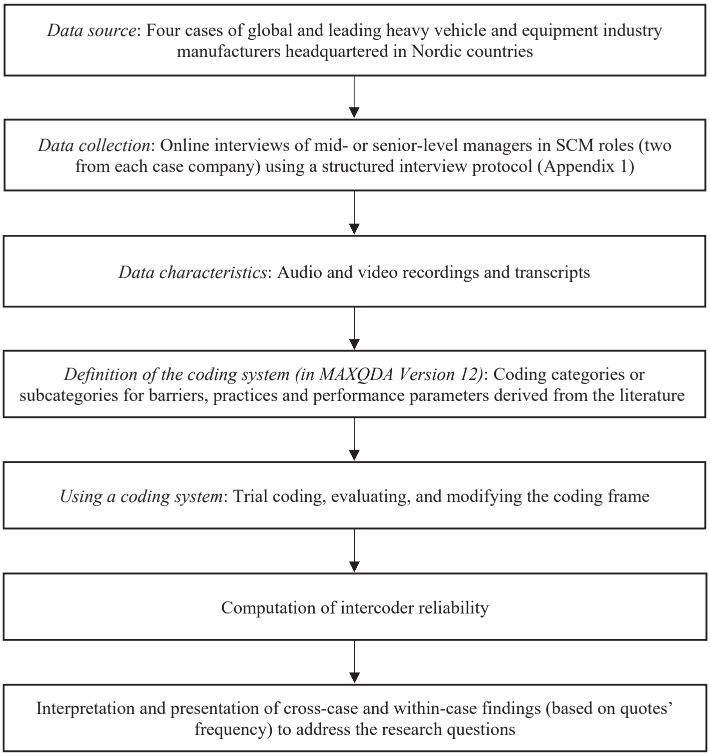
3.3 Secondary data collection

In addition to the interviews, complementary information on the studied cases was collected for data triangulation to increase the results' reliability. The secondary data included companies' annual and sustainability reports and information provided on the companies' websites.

4. Results

4.1 Case A

Case A was a provider of cargo handling solutions. It employed over 10,000 people, operated in over 100 countries and recorded revenue of over 3 billion euros. It also operated in three business areas. The first area included equipment for cargo handling and automated terminal solutions, software and services, which were used in ports, terminals and various industries. Additionally, the company provided related services, maintenance and intelligent solutions. The second area focused on loading and lifting solutions for land transport and delivery. Finally, the third area provided products, engineering solutions and services for maritime



Source(s): Authors own work

Figure 2.
Qualitative content analysis process

use. The company purchased materials, parts and components – such as steel structures, electrical components, power line components and various mechanical components – from a global supplier base.

The company's SSCM focus was to achieve carbon neutrality by 2030. It boasted a 'Class AA' rating by Morgan Stanley Capital International (MSCI) and a 'platinum' rating by Ecovadis while maintaining a Carbon Disclosure Project rating of 'B' in 2020 and 2021. Case A followed the requirements for sustainability disclosures per Global Reporting Initiative (GRI) standards and the Sustainability Accounting Standards Board's (SASB's) industrial machinery and goods standards in 2020. The company's key science-based target (based on a 2019 baseline) was to cut its absolute scope 1, 2 and 3 emissions by 50% by 2030. This goal required a focus on the upstream supply chain and the use phases of sold products, which accounted for 95% of the company's emissions.

Case A had established programmes for supply chain decarbonisation, supplier risk assessment, hazardous substance management (e.g. lithium batteries) and suppliers' involvement in design for-environment (DfE) initiatives. As the sustainability development manager emphasised, *'Climate mission is on the company-level, and then it is divided according to those scopes of emissions that we have, so there is a different team working on our own emissions and on the supply chain scope upstream'*. The company had a long-established supplier code of conduct (CoC) and audit programmes, including labour rights requirements. The same manager stressed, *'It's kind of living programmes. We are always learning from the previous years and trying to optimise it. We keep on updating our risk assessment approach. So, that is running programmes, and in general, I say it's human rights, a safeguarding within a supply chain'*.

The company's perspective on the sustainability performance related to economic metrics was expressed by its sourcing director: *'A more crucial part of the business, on our side, is the refurbishment of the old products, which is a part of the sustainability initiative'*. The key environmental performance indicators of SSCM were associated with climate (e.g. the carbon footprint or handprint and the reduction of hazardous substances). Meanwhile, the key internal barrier to the wider adoption of SSCM was a lack of understanding of supply chain-level sustainability measures. The same director pointed out: *'As I said, the definitions are not clear. There is so much different kind of sustainability. Is the focus area environmental, social, economic, health or safety? What is the focus area?'* Another major barrier was a lack of expertise in sustainability-related matters at both the supplier and focal-firm levels: *'Then, really, the expertise lacking in sustainability is more data management and analytical skills. Connecting sources of information, making it accurate, maybe some kind of visual presentation so that we can also have a good discussion and, you know, targets-setting as well'*. Evidence of suppliers' resistance towards SSCM initiatives was also found: *'It could be related to the market position because, if you don't have an influence on your suppliers, for example, then maybe it's difficult to push it'*. Other external barriers included uncertainty concerning sustainability-related regulatory requirements and the market for green products.

4.2 Case B

Case B was a leading company in the lifting business, serving different types of customers in manufacturing, the process industries, ports, terminals and shipyards. It had over 15,000 employees in 50 countries, and its revenue was over 3 billion euros. All the activities included various types of industrial cranes, the container handling industry, spare parts and maintenance services for all types of industrial cranes and hoists. The company utilised global sourcing and purchased items, such as electronics and steel parts.

For Case B, sustainability was structurally part of the company's Health, Safety, Environment and Quality (HSEQ) function and governed by a board-level committee.

The five components of Case B's sustainability strategy were a safe workplace and product, sustainable or green offerings, climate matters, a diverse and inclusive workplace and responsible business behaviour. The health and safety of the company's own operations and across its supply chains were strategic priorities, as several interview statements and the company's sustainability report indicated – for instance, *'there is no work so urgent or important that it cannot be done safely'*. To enable safety, the company had invested in research and technology development for supply chain solutions, such as remote operating systems and mobile applications. It used technology solutions to gather real-time data on health and safety indicators, such as total recordable injuries (TRIs) and the serious injuries and fatalities (SIFs) of supply chain partners. Case B's social responsibility manager (SRM) stated, *'We check year-on-year reduction of SIF exposure from own and supply chain partners'*. Additionally, the company recorded diversity and inclusion metrics at the factory and supply chain levels, as part of its supplier CoC document explained: *'Then, for diversity and inclusion, there are also a wide set of metrics on gender on different levels of the organisation, be it in the board and the executive management in the leadership, in line managers or suppliers. Along all, we look at age, nationalities, and disabilities'*. The company's environmental performance targets included the use of renewable energy, as well as the reduction of emissions and energy. Case B's service business focused on extending equipment's lifetime via maintenance and repair, remanufacturing, modernisation and – eventually – recycling at EoL. The company had EoL targets related to reuse, remanufacturing and recycling.

Key SSCM practices included internal audits and external reporting (e.g. materiality analysis as part of an annual report and a task force on climate-related financial disclosures). These practices were controlled by the compliance and ethics committee at the board level. Case B provided training on lifesaving, observation monitoring and legal compliance for suppliers. It helped its suppliers adopt approaches and use environmental-product declarations to communicate its products' environmental aspects. Case B's service business model was built on resource-sharing and reusing principles.

The SSCM barriers identified for the company included a lack of sustainability-related expertise, the cost implications of SSCM initiatives and a limited information flow between the company and its supply chain partners. As Case B's SRM indicated, *'There are some very specific topic and skills – for example, this lifecycle assessment – where we lack.... So, there needs to be a lot of engineering type of knowledge. Then, on this substance compliance. It's then specific knowledge on the like, chemistry type of knowledge even'*. They added, *'Renewable electricity that is typically a cost, not even an investment, if you buy a certificate type of thing, making the business case for that'*. Another barrier was access to the correct data from supply chain partners at the right time for target-setting and risk assessment: *'to be able to set these science-based-targets, it is not easy to get from the supply chain when there is, maybe, something like 15,000 suppliers'*.

4.3 Case C

Case C provided underground machines, services and support. It employed over 1,000 people, operated in over 33 countries and recorded a revenue of over 100 million euros. The company aimed to lead the transformation into digitalised and sustainable underground mining and tunnelling. Its offerings included equipment, construction chemicals and rock reinforcement and services, while its main factory was located in Finland, and its suppliers were mostly located in Europe. However, some suppliers and subcontractors were located close to the factories in Chile and India.

Case C's environmental sustainability targets focused on the impacts of its product range throughout their lifecycles, as the vice-president of sourcing and purchasing indicated, *'The CO2 emissions happen during our customers use our machines. So, how we can reduce the* *lifetime emissions of our machines have a much bigger impact than what happens in our own [internal] operations and in our upstream supply chain'.* For example, inefficiencies in the concrete-spraying process during customers' mining operations caused significant waste in CO_2 emissions. The company disclosed carbon-handprint ratios as its supply chain's key environmental performance indicator. Employee safety was also a key sustainability criterion. To reinforce this safety, the company had targets for a lost time incident frequency rate (LTIFR) for its operations, service centres and supply chain. The company also ran research programmes involving supply chain partners as indicated by the vice-president: *'In collaboration with supply chain partners, we developed battery-electric fleet, and we launched the offering in 2019'.*

The suppliers were audited to meet supplier CoC requirements in order to address conflict material, human rights and other legal compliance issues. The company had an internal reporting mechanism, including health, safety and environmental reporting tools, but it did not disclose this information to external environmental, social and governmental (ESG) evaluators. Customers' unwillingness to pay for sustainable equipment was an important SSCM barrier, as Case C's global head of HSEQ stated: *'So, we have to compete with companies who do not necessarily provide sustainable features.... There are customers who only care about the acquisition cost of equipment, and what happens over the lifetime is not at all important to them'.* Furthermore, as the vice-president of sourcing and purchasing explained, *'Green is not cost-effective. So, initially, there may be implications of cost which we need to probably, you know, agree as a business... we can't put the burden on our suppliers'.*

4.4 Case D

Case D was a manufacturing and technology company with over 30,000 employees, global operations and a revenue of over 8 billion euros. The company was divided into four business areas: manufacturing and machining solutions, mining and rock solutions, rock processing solutions and materials technology. Its offerings included tools and tooling systems, solutions for mining and construction, advanced stainless steel and special alloys and industrial heating products. Case D's supplier base was global, and it included thousands of suppliers.

Case D's SSCM initiatives supported company-level sustainability goals for circularity, climate, people and fair play. The company used a set of metrics to evaluate supply chain partners' performance in pursuing these goals. For example, waste recovery rates and circularity in business models were among the environmental metrics. Several people-related performance indicators were used, such as lost time incident (LTI), TRI, exposure hours and work-related illness at factories and supplier sites. A key climate-related measure was a reduction in CO_2 emissions through energy efficiency and clean energy initiatives.

The company's SSCM practices focused on involving supply chain partners in product design to reduce customers' carbon footprints. For example, the company had developed the world's first battery loader to reduce emissions and heat, as well as a mining automation system for safer and more productive operations. 3D printing was used to produce lighter products using less raw material. The company also had a recycling programme for worn parts. Since 2016, Case D had been publishing an integrated annual report, following the GRI and Dow Jones Sustainability Index. It also used internal audit mechanisms for hazards and risk assessments.

As many interview statements reflected, the cost implications of Case D's sustainability initiatives were the most significant barrier to the company's SSCM adoption. For instance, the sustainability and compliance lead stated, *'Money, money, money! Green choice has a higher price, and we need investments. Basic diesel versus biodiesel, a few per cent extra cost is* *big in high volumes'*. Another barrier was variance in sustainability regulations across different markets as mentioned by the sustainability and compliance lead: *'recognise different regulations, laws that different countries have, is a challenge'*. Tables 3–5 synthesise the findings from the four case companies.

5. Discussion

Table 6 synthesises the case studies' findings. First, it represents the comprehensive coverage of SSCM's BPP measures across the four case companies. Although each case company emphasised different SSCM attributes, all were reasonably evidenced as either barriers, practices or performance indicators. Further, we observed commonalities across cases that enable our findings to be generalised to the HVEI. For instance, strong evidence of a lacking information flow as the main barrier, as well as supplier CoC, audit programmes and environmental design as key practices across all four cases, reinforces these elements' prominence in the HVEI. Categories were rated as *high*, *medium* or *low*, based on the extent of evidence found both within and across cases (as Section 3 explained).

The cross-case analysis results indicate supply chain cost implications, an inadequate flow of information between a focal firm and its supply chain partners and regulatory uncertainty as the strongly evidenced barriers to SSCM in the HVEI. Arguably, key customers in the HVEI – such as mining companies, harbours and ports – are often cost-driven and do not accept higher costs. This behaviour differs from the light vehicle sector, for which customers are environmentally conscious and regulators force manufacturers to reduce CO_2 emissions (Fraser *et al.*, 2020; Mathivathanan *et al.*, 2018). HVEI products, on the other hand, are either fixed structures or used in off-road environments, and they do not follow the CO_2 standards that light vehicles must. Further, these products are expensive, and their lifespans last longer than those in the light vehicle industry (Saidani *et al.*, 2019, 2020). Therefore, we recommend that the total cost of ownership (including operations and maintenance costs) should be considered for an HVEI product's whole lifecycle. This practice would ensure that such factors as product weight and lifetime energy consumption would be considered in customers' buying decisions. Furthermore, in many cases, HVEI products

Table 3.
Summary of findings on SSCM barriers

Case	SSCM barrier Internal	External
A	Unclear definitions: • Lack of clarity on an organisational-level definition of *sustainability*, focus areas and measures Lack of specialised knowledge: • Shortage of skills for life-cycle assessment (LCA), materials' chemistry and environmental design	Supplier resistance • Incapability and unwillingness of small and medium-sized suppliers Regularity uncertainty • Cross-country differences in regulations • Suppliers' unawareness of the latest regulations
B	Lack of specialised knowledge on • Information flow and access • Supplier risk assessment • Data integration issues	Regulatory uncertainty due to • Frequent changes • Diversity in substance requirement norms
C	Cost problems • Green initiatives' implications for supply-chain costs	Customer issues with • Awareness of and willingness for sustainable or green products
D	Supply chain cost implication	Regulatory variance

Source(s): Authors own work

Case	SSCM practices Policy	Programme	Procedure
A	Internal reporting: • Regular reporting by ethics and compliance committee (board-level committee) External reporting: • MSCI; Ecovadis; GRI index; SASB indicators	Audit programme: • Supplier code of conduct and audit programme, based on international codes Hazardous substance management: • Software for collecting substance data	Environmental design, including: • Eco portfolio • Refurbished equipment Management systems, standards, and certifications: • ISO 14001, ISO 9001, ISO 45001
B	Internal reporting: • Safety and environment reporting tool • Environmental risk assessments External reporting: • Annual report and sustainability reporting • Investor questionnaires	Audit programme: • Supplier code of conduct • Risk-based know-your-counterparty process Science-based target initiative: • Lessen climate risks • Cut emissions and improve the low-carbon portfolio	Environmental design: • Low-carbon and circular products • Preventive maintenance programmes Research and technology development: • Real-time equipment data • Data science lab • Utilising smart technologies for eco-efficient features
C	Internal reporting: • Safety and environment reporting tool • Environmental risk assessments	Safety campaign on: • Zero harm • Building the safest places underground	Research and technology development: • Virtual reality simulator for tunnelling operations (concrete spray)
D	Internal reporting: • Hazard analysis External reporting: • GRI and Dow Jones Sustainability Index	–	Research and technology development • Mining automation systems • Smart features

Source(s): Authors own work

Table 4. Summary of findings on SSCM practices

are customer-tailored and low-volume. Therefore, their supply chains are less mature than those of light vehicles, for which much is invested in supply chain coordination, based on lean principles and connected information systems (Pereseina *et al.*, 2014).

Due to supply chain fragmentation, managing an information flow is challenging. Additionally, in the HVEI, large original equipment manufacturers (OEMs) often follow strict sustainability standards for their first-tier suppliers. They can expect a cascading effect through the supply network, which would require end-to-end visibility of the supply chain. Such visibility is challenging and time-consuming to implement in practice. Unlike the light vehicle industry, which has been set up competitively and progressively and is characterised by several large OEMs that have strongly driven their sustainability initiatives for several years, HVEI OEMs have just recently started to take steps towards progressing their sustainability efforts. Not all customers require OEMs to deliver sustainable products and follow sustainability standards. Changing the industry's culture and eliminating the legacy issues that hinder sustainability in its supply chains will also take time.

As the empirical evidence suggests, a 'lack of clarity on *sustainability*'s definition and indicators', 'market or customer uncertainty' and a 'lack of sustainability-related expertise'

Case	SSCM performance Environmental	Economic	Social
A	Carbon footprint and handprint: • Scope 1, 2 and 3 emissions (tonnes of CO_2) • Emission intensity or sales (tonnes of CO_2 or million euros)	Eco portfolio sales or total sales	Health and safety: • Industrial injury frequency rate (operations and supply chain) Human rights: • Code of conduct, based on the United Nations' *Guiding Principles of Human Rights*
B	Circularity: • EoL indices (reuse, remanufacture and recycling)	Eco portfolio sales/total sales	Safety: • Total recordable injuries • SIF
C	Carbon handprint • The carbon footprint reduction that a customer attains	Eco portfolio sales/total sales	Safety: • LTIFR
D	Carbon, energy, water, and waste: • Renewable and non-renewable • Energy intensity • Direct and indirect CO_2 emissions • Water withdrawn and discharged • Waste (hazardous and non-hazardous)	Eco portfolio sales/total sales	Health and safety: • Lost time incident • Total recordable injuries • Hazards and incidents • Work-related illness • Hazardous material use • Diversity and inclusion metrics

Source(s): Authors own work

Table 5. Summary of findings on SSCM performance

constitute medium-level barriers. Regulations and requirements vary across countries and customers, making common definitions difficult (Chirra *et al.*, 2021). For example, national regulations for the EoL management of HVEI products differ in the European Union, North America and emerging countries (Saidani *et al.*, 2019, 2020), which makes defining globally accepted EoL processes for these products challenging. *Sustainability* can still be considered a strategy-level concept in the HVEI, and it must be defined at tactical and operational levels to establish concrete targets and indicators. A lack of sustainability-related expertise, in turn, presents a challenge, hindering the successful implementation of SSCM practices and the evaluation of performance outcomes. This challenge is both general and industry-specific because sustainability expertise requires a combination of general knowledge about sustainability and industry-specific skills regarding technology, design and business processes.

Interestingly, in the HVEI context, we found no evidence of a 'lack of top-management commitment', which has been a commonly reported barrier in many sectors (Fraser *et al.*, 2020; Mathivathanan *et al.*, 2018). However, based on our study's results, a gap exists between *strategy-level* and *tactical and operational* implementation. Also, a 'lack of technology' and 'supplier resistance' were rated as less significant barriers. Sustainability is a growing trend in energy-intensive industry sectors, including the HVEI (Saidani *et al.*, 2019, 2020), and senior managers are pressurised to show their commitment to achieving global sustainable development goals. However, since these sustainability implementations across the supply chains remain in their early stages, technology and supplier resistance may emerge as barriers only later. These barriers may be encountered once basic definitions and structures have been established and the need to optimise performance and expand sustainability implementations has gained ground.

Our research indicates some of the current barriers to SSCM in the HVEI; however, these barriers are evolving. In this regard, such strategies as the adoption of a lifecycle approach (i.e. pre-life, life and EoL stages) in determining the total cost of ownership for the HVEI help

Category or subcategories	Evidence	Companies Case A	Case B	Case C	Case D
Internal SSCM barriers					
Lack of clarity on *sustainability*'s definition and indicators	Medium	+++	+	+	++
Lack of top-management commitment	Low	+	++	+	
Lack of sustainability-related expertise	Medium	++	+++	+	
Lack of technology	Low	+	+		
Supply chain cost implications	High	++	++	+++	+
Information flow and access	High	+	+++	+++	+++
External SSCM barriers					
Supplier resistance	Low	++			
Market or customer uncertainty	Medium	++	+	+++	
Regulatory uncertainty	High	++	++	+++	++
SSCM practices					
Policy					
Sustainability council	Low		+		
Internal audits and reporting	High	+	+++	+	+
External audits and reporting	Medium	+	+++		+
Research and technology development	High	+	+++	+	++
Programme					
Supplier decarbonisation programme	Low	++			
Hazardous substance management	Medium	++		+	+
Supplier training and award	Medium	++		++	++
Supplier diversity and inclusion programme	Low		+		+
Science-based target initiatives	Medium	+	++		+
Supplier code of conduct and audit programme	High	+++	+++	+	+
Supplier health and safety programme	Medium		+	+	++
Procedure					
Supplier risk management	Low	+			
Supplier selection procedure	Low	+	+		
Design for environment	High	+++	+++	+++	++
Management systems, standards and certifications	Medium	++	+		++
SSCM performance					
Economic					
Supply chain cost	Low	+	+		
Competitive advantage or green products' sales	High	+	+	+++	+
Social					
Labour or human rights	Medium	++	++	+	
Health and safety	High	+	++	++	++
Diversity and inclusion	Low		+		
Environmental					
Circularity	Medium		++	+	+
Hazardous and toxic substance use	Medium	++	+		+
Waste generation	Medium	+	+	+	+
Water usage	Medium		+	+	+
Energy consumption	Low		+		+
Carbon footprint and handprint	High	+++	++	+++	++

Note(s): + = superficially evidenced; ++ = evidenced; +++ = strongly evidenced
Source(s): Authors own work

Table 6.
Synthesis of cross-case analysis for SSCM's BPP

deal with cost-related barriers. It is particularly important in the HVEI because of the long lifetimes of vehicles and machinery. For example, lifting machinery – such as cranes – is expected to work for 40 years or more. Therefore, the integration of real-time monitoring for supply chain logistics is sorely needed in the HVEI. This need has arisen because HVEI supply chains are characterised by multiple suppliers that use their own logistic partners. This intricate setup makes the accurate monitoring of information exchanges among these suppliers and their logistics partners complex. Further, such an approach is ill-suited to handle this complexity without sound collaboration among participating parties, including focal firms, 3PL and technology vendors.

We also found substantial evidence of focal firms' policies, programmes and procedures contributing to their SSCM practices. Policies for regular internal audits and reporting on sustainability matters were found to be the most apparent mechanisms. Supplier auditing and reporting are common practices across the light vehicle industry, as well as other industries, so they are not unique to the HVEI (Mathivathanan *et al.*, 2018). Even at the programme level, the HVEI seems to follow most industries' trend of reinforcing supplier audits and supplier development in supply chains. At the procedure level, the DfE approach and research and technology development were identified as common practices particular to the HVEI. The focus on product sustainability and safety during its usage is unique to the HVEI, and this lifetime sustainability aspect could be strengthened even further at the companies we investigated. HVEI products lifetimes are longer than many other industries' product lifetimes, so the potential sustainability improvement impacts could be vast. Moreover, most HVEI products are used in dangerous environments (mines, ports and industrial facilities), making product safety an essential concern.

Concerning SSCM performance in the HVEI, the sale of green products was the most-reported economic indicator across cases. This key performance indicator (KPI) is similar to the KPI for light vehicles, for which manufacturers assess and report growth in their eco-portfolio sales. However, as the light vehicle industry has shown, the rollout of electricity-powered products also requires supporting infrastructure (i.e. charging stations), which may slow sales growth in some markets. Health and safety metrics for operations, service centres and supply chains were the most-reported social sustainability indicators. Product safety is paramount to the HVEI, and companies must convince customers that they take safety seriously across their operations and supply chains – not just for their final products. Concerning environmental and climate-related metrics, all this study's cases showed evidence for carbon- and energy-related measures, with some evidence for the use of circularity-related KPIs. Enhancing product and material circularity presents ample opportunity for the HVEI since steel is abundantly used in the industry's products.

Further, since HVEI product lifetimes are long, the cost of ownership and CO_2 emissions across a product's whole lifecycle is important. The carbon-handprint approach (i.e. assessing positive climate impacts) is a new method that is also emerging in the HVEI. It allows for the evaluation and communication of customers' greenhouse gas reductions through the use of green products (Grönman *et al.*, 2019).

6. Conclusion

In the HVEI, supply chains' complexity and considerable environmental and economic impacts make examining these supply chains from a sustainability perspective relevant. This study's objective was to analyse the SSCM BPP in the HVEI. The scientific literature was analysed systematically to identify the general BPP indicators for sustainable supply chains in order to achieve this study's research objectives. Subsequently, the BPP indicators were investigated empirically through the cases of four multinational HVEI manufacturers.

This study offers four main theoretical contributions. First, since the literature includes few empirical studies on HVEI supply chain issues, our study helps broaden the SSCM literature by explaining sustainability considerations for supply chains in this sector. The SSCM concept has been researched far less for heavy vehicles than for light vehicles, and the current study helps fill this gap while providing interesting comparison points between these industries. Second, whereas Fraser *et al.* (2020) and Mathivathanan *et al.* (2018) highlighted environmental consciousness and regulators' role in decreasing CO_2 emissions in the light vehicles sector, we found that the HVEI focuses more on costs. Additionally, the variations in regulations among different countries and supply chains' immaturity were found to constitute barriers to SSCM adoption, supporting the findings of Pereseina *et al.* (2014). Third, while our findings that supplier auditing and reporting are common practices support the prior SSCM research, the unique, HVEI-specific factors – such as the importance of safety and product-lifetime sustainability – were also identified and elaborated upon. Fourth, we found that top HVEI managers are committed to SSCM, differing from reported findings for the light vehicles sector. However, we identified a persistent gap between SSCM strategy and implementation, and SSCM can be concluded to still be in its early phase for the HVEI. Accordingly, we expect the sector to face different barriers as it evolves, in line with the findings of Ayati *et al.* (2022).

Our study also presents some practical implications. First, the insights it has provided can help HVEI firms understand and overcome typical SSCM barriers in their industry and develop, deploy and optimise their SSCM strategies and practices. Managers can use this knowledge to anticipate challenges to supply-chain sustainability, identify appropriate mechanisms to accelerate their transition into a sustainable business and effectively measure their performance outcomes, in line with the industry's prevalent trends. These approaches can help managers overcome the gap between SSCM strategy and implementation. Second, we recommend that HVEI companies emphasise total-cost-of-ownership aspects to help customers make more environmentally friendly purchasing decisions. Third, HVEI products are becoming more electric, and this transition necessitates supporting infrastructure. This shift, in turn, requires companies to acquire new resources, skills and partnerships in order to ensure that the necessary capabilities are available – for example, to operate batteries and charging stations. Fourth, national and regional legislators must focus on harmonising regulations and legal requirements to support the HVEI's sustainability transition. Fifth, since the HVEI's SSCM remains in an early phase, companies have significant potential to develop their circularity solutions, such as product and component reuse and remanufacturing.

The present study also faced some limitations and presents some opportunities for future research. Its limitations include the limited number of companies it analysed and its focus on a single geographical region, which make generalising the study's findings difficult. The studied cases were focal companies in their supply chains. This selection was well justified for an explorative study of the HVEI; however, in addition to addressing this study's small sample size and geographical limitations, recommended future studies could investigate SSCM BPP at smaller companies by employing a similar method and research how sustainability can be implemented in end-to-end supply chains. Finally, future studies should also investigate operational sustainability practices, as well as the overall sustainability and circularity transition at different types of organisations, supply chains and geographical areas.

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Appendix

Interview protocol and instructions (Source: Authors own work)

Aim: To get a comprehensive overview of the supply chain practices targeting the heavy vehicle and equipment industry from the perspective of environmental, social, and economic sustainability. We also want to shed light on the barriers to developing supply chain sustainability and the performance of these initiatives.

General instruction: Please answer based on your best knowledge. Please be aware that there is no right or wrong answer.

Confidentiality: No information about the company name will be revealed. The interview will be recorded and transcribed to extract the most relevant parts of your valuable feedback.

Support material: We have shared the research background with a high-level list of sustainable supply chain barriers, practices, and performance indicators that emerged in our systematic screening of the scientific literature.

A. General information on the interviewee and case company

(1) What is your name and role at the organisation?

(2) What length of experience do you have in this position?

(3) What length of experience do you have at the company and in the industry?

(4) What products and services does your company produce?

(5) How is the supply chain structured?

(6) How has the company evolved in recent years?

(7) What are the high-level sustainability goals of the company?

B. Barriers to the adoption of sustainable supply chain initiatives at the case company

(1) What barriers is your company facing regarding sustainability in the supply chain?

(2) In which part of the supply chain did this challenge emerge?

(3) Which supply chain actors have been affected by this barrier?

(4) Has your company tried to overcome the barrier?

(5) Which barriers (up to three) are the most relevant, in your opinion?

(6) What is the priority of dealing with these barriers?

(7) What skills and knowledge are needed to deal with these barriers?

C. Sustainable supply chain initiatives or practices at the case company

(1) What type of sustainable supply chain initiatives are ongoing or have been undertaken in the past?

(2) How were those initiatives set up?

(3) Where in the supply chain have those activities been running?

(4) What are the most important sustainable supply chain initiatives (up to three)?

(5) What skills and knowledge are needed to implement the SSCM practices?

D. The performance of sustainable supply chain initiatives at the case company

(1) What type of indicators or metrics does your company use to measure sustainability initiatives' performance in the supply chain?

(2) What are the most important indicators or metrics (up to three)?

(3) How did those activities or initiatives that you described earlier perform?

(4) How was the performance reported (databases, ERP systems)?

(5) What skills and knowledge are needed to measure the SSCM initiatives?

Thank you for your time. We will send our notes for further validation. The results of the cases will be systematised and finalised anonymously. We will share the final report with you.

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