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Supplier sustainability assessment in the age of Industry 4.0 – Insights from the electronics industry

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ABSTRACT

Achieving transparency of the social and environmental impacts of industrial production poses significant obstacles for companies operating in complex global supply chains. They often do not possess sufficient information of other actors, especially at lower tiers in the supply chain. In recent years, data collection and information exchange in industry has been increasingly assisted by digital technologies, coining the term Industry 4.0. However, it remains largely unknown how companies try to foster transparency in their supply chains and how digital technologies are utilized for this purpose. In this study, we employ a qualitative, interview-based approach from both buyers' and suppliers' perspectives to investigate practices of supplier sustainability assessments in the electronics industry as well as their current and envisioned utilization of digital technologies. With regard to the exchange of sustainability-related information, we find that buying firms do not consistently check for the availability of digital interfaces to suppliers. Systematic and well-structured collection of such data is rare in suppliers, relying on manual self-assessments and lacking the means of automated data collection. This poses difficulties for buying firms to ensure validity of sustainability performance claims, highlighted by the fact that not all buying firms analyze suppliers' self-assessments. To overcome such issues, ongoing industry-wide efforts of standardizing sustainability requirements should be extended to include strategic considerations of streamlining technology implementation to enhance data availability and validity.

1. Introduction

Global supply chains (GSCs) are becoming longer, more complex and more fragmented (Mena et al., 2013). In the light of reports about environmental scandals and exploitation of workers, companies operating in GSCs are facing increasing pressure to provide transparency regarding the sustainability of their business practices (Mol, 2015; Tachizawa and Wong, 2015). Egels-Zandén et al. (2015) propose that supply chain transparency comprises corporate disclosure of not only the companies involved in producing a product (traceability), but also includes information about the sustainability conditions at involved suppliers as well as buying firms' purchasing practices. Similarly, Gardner et al. (2019) hold that information about companies involved in the supply chain and their interlinkages is but one aspect of transparency, which further includes (among other aspects) information about social and environmental impacts of supply chain activities. Notwithstanding the increasing relevance of companies to assess their suppliers' sustainability performance, managing supplier information is a complex task that includes the assessment of a broad variety of information (Govindan et al., 2013), aiming to gain an encompassing perspective on supplier performance. Previous research has found heterogeneous perceptions of practitioners concerning the relative importance of different sustainability indicators (Badri Ahmadi et al., 2017), posing the overarching question if sustainability of suppliers has indeed become a more relevant selection criterion for supply chain partners.

Companies are struggling to achieve transparency of social and environmental implications of production in their supply chain since they frequently do not possess sufficient information on the procedures of their supply chain partners (Busse et al., 2017; Foerstl et al., 2018). Carter et al. (2015) highlight that supply chain visibility decreases with increasing physical and cultural distance, as companies face severe difficulties in reaching suppliers below first-tier suppliers (Koberg and Longoni, 2019). Few studies have investigated how companies aim to perform supplier sustainability assessments and achieve transparency of supply chain actions. Busse et al. (2016) show that suppliers are prone to misinterpreting data requirements regarding sustainability, unveiling contextual barriers. Moreover, Wilhelm

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et al. (2016) highlight the need to actively integrate first-tier suppliers in supplier sustainability assessments in order to ensure proliferation of reporting requirements in lower supply chain tiers. Thus, selecting and evaluating suppliers is subject to a significant degree of uncertainty (Li et al., 2015) and there is scarce empirical evidence regarding the efforts of companies to provide transparency on sustainability in GSCs (Egels-Zandén et al., 2015). More specifically, prior research suggests that this relates to a twofold issue warranting further research on the boundary conditions of supplier sustainability assessment: Firstly, drivers and mechanisms that foster suppliers' sustainability engagement are relatively unexplored (Foerstl et al., 2015). Secondly, assuming suppliers do in fact aim to improve their sustainability performance, little is known about the circumstances that either discourage or deter suppliers from sharing sustainability-related performance information with supply chain partners (Jira and Toffel, 2013).

The current circumstances in GSCs thus create new needs for reliable, comprehensive, verified and credible information regarding the sustainability performance of supply chain actors (Boström et al., 2015), raising the question of the necessary technological means to acquire such information. In recent years, research has increasingly focused on sustainable supply chain management (SSCM) (Pagell and Shevchenko, 2014), which has been defined as "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring and Müller, 2008). Likewise, the use of digital technologies in SCM has attracted substantial interest among scholars and practitioners (Kache and Seuring, 2017). However, there is a dearth of insights on the use of digital technologies for SSCM (Thöni and Tjoa, 2017; Garcia-Torres et al., 2019). In general, the SSCM literature has thus far largely excluded technological issues (Chalmeta and Santos-deLeón, 2020). It has often been stated that new digital technologies associated with the term "Industry 4.0", such as cyber-physical systems (CPS), big data analytics (BDA) and the internet of things (IoT), may have disruptive effects on information exchange in GSCs (Kiel et al., 2017), which can be connected to use cases of SSCM and supplier sustainability assessment (Manavalan and Jayakrishna, 2019). For instance, cloud-based platforms enable real-time assessments of products' life cycles. Furthermore, the feasibility of employing blockchain-based solutions to improve validity of sustainability claims is being investigated (Rane and Thakker, 2019; Saberi et al., 2019). Although linkages between supplier sustainability assessment and the utilization of digital technologies in SSCM have been proposed, it has received little attention, especially with regards to empirical investigations (Ghadimi et al., 2019; Giuffrida and Mangiaracina, 2020).

Hence, we aim to bridge this gap by investigating current practices of supplier sustainability assessment in the electronics industry. We employ a qualitative, interview-based approach separately analyzing both buyers' and suppliers' perspectives. As outlined above, we argue that supplier sustainability assessment in GSCs relates to at least three dimensions of transparency that we aim to investigate in this study. Firstly, further insights are required concerning *what* aspects of suppliers' performance buying firms aim to be more transparent about. Secondly, there is still uncertainty as to *why* supplier sustainability assessments are performed in a certain way and why specific information is gathered and shared (or why not). Thirdly, little is known about *how* companies perform supplier sustainability assessments and which (digital) tools could be employed for improved supply chain transparency on sustainability. Accordingly, we pose the following research questions (RQs):

(1) Which performance indicators do companies assess in suppliers, and what is the relative importance of sustainability-related and digitalization-related performance in suppliers?
(2) What are the main boundary conditions framing the process of supplier sustainability assessments in the electronics industry?
(3) What are current practices in supplier sustainability assessment, and what role do digital technologies play now and in the future?

This paper is structured as follows: We first describe the current state of research on a) SSCM and supplier sustainability assessment, and on b) related boundary conditions, as well as on c) digital solutions for supplier sustainability assessment and monitoring. After summarizing our methodological approach, we elaborate our findings and discuss answers to our research questions before ending with concluding remarks.

2. State of the art

Our study draws on, and thus tries to unite, different strands of research on which we will elaborate in the following. Firstly, the discussion around SSCM (Seuring and Müller, 2008) frames our understanding of supplier sustainability assessment (Schöggl et al., 2016) as well as the challenges associated with establishing, monitoring and maintaining sustainability standards (Pagell and Wu, 2009) in GSCs. Secondly, there is increasing interest in the boundary conditions framing supplier sustainability assessment, which relate to both issues of sustainability measurement in supply chains (Mura et al., 2018) and inter-organizational information exchange on sustainability (Dahlmann and Roehrich, 2019). Thirdly, research on the use and proliferation of digital technologies in companies and industry (Beier et al., 2020) has portrayed a variety of opportunities from which SSCM may benefit (Thöni and Tjoa, 2017; Muñoz-Villamizar et al., 2019) and thus improve transparency of sustainability-related impacts of actors along the supply chain and of potentially unsustainable practices (Garcia-Torres et al., 2019; Ebinger and Omondi, 2020).

2.1. Supplier sustainability assessment and monitoring

Procurement and supplier management are integral parts of SCM and play an important role in achieving sustainable supply chains (Lu et al., 2018). Research has highlighted the role of "lead firms", describing their powerful position in supply chains, in governing and enforcing sustainability strategies among actors in GSCs (Khattak and Pinto, 2018). In the context of SSCM, companies may follow different approaches to foster sustainability, ranging from collaborative problem-solving to monitoring, inspection and risk minimization (Vachon and Klassen, 2006). The scope of our study relates more closely with the latter approach of (supplier) sustainability monitoring, which has also been termed "supplier (sustainability) assessment" (Gimenez and Sierra, 2013) which we will use synonymously henceforth. Supplier sustainability assessment encompasses actions of a focal firm such as gathering information to monitor and evaluate the sustainability performance of suppliers (Gimenez and Sierra, 2013). Different tools have been established to perform supplier sustainability assessments (Lee and Kashmanian, 2013). Fraser et al. (2020) state that companies usually follow an escalation scheme, starting with supplier codes of conduct followed by measures of monitoring and assessment, such as self-assessment questionnaires and sustainability audits (Fraser et al., 2020a, 2020b). Companies may include a broad variety of aspects to be assessed in terms of sustainability. In our study, we are specifically interested in the social and environmental aspects of sustainability. Fritz et al. (2017) compile sustainability aspects for supply chain data exchange, ranging from energy-efficient production and emission reduction to occupational safety and prohibition of child labor. Moreover, a range of industry standards and legal norms exists to improve both social and environmental sustainability. The European Union's RoHS directive regulates the use of hazardous substances

in electronic products, whereas the U.S. Dodd Frank Act's Section 1502 addresses the issue of conflict minerals (Jameson et al., 2016). Countries are also increasingly demanding due diligence, as reflected by the German "Supply Chain Act" for instance, requiring transparency on social and environmental issues. Due to the broad scope of potential sustainability issues to monitor supply chains in the face of limited resources, companies face difficult decisions of determining supplier selection criteria and weighing their importance. This requires prioritization, and conversely the omission of indicators deemed irrelevant. For instance, Ahmadi et al. (Badri Ahmadi et al., 2017) find that practitioners have very different perceptions of the relevance of specific social sustainability indicators. More generally, additional research is called for concerning sustainability criteria specified in different contexts of global sourcing (Ghadge et al., 2019) and on how their relevance is gauged in contrast to traditional performance indicators which have dominated decision-making for the majority of the past (Ho et al., 2010).

Given the broad scope of indicators relevant for the selection and assessment of suppliers, not only concerning sustainability but also more traditional (economic) performance indicators, deciding who to engage with in business relationships can be a complex endeavor. Hence, a variety of approaches for multi-criteria decision-making problems under uncertain conditions have been developed, using methods such as rough set theory and others (Lu et al., 2018; Zhou and Xu, 2018; Schiessl et al., 2020). Nevertheless, accessibility of validated data regarding their performance is limited (Azadnia et al., 2015). This is particularly relevant in GSCs where large amounts of data on suppliers' prior and current performance can be used, also for predictive analyses, given the application of suitable data analysis methods (Li et al., 2015). Hence, this also raises the question if digital channels for the exchange and subsequent analysis of performance criteria are leveraged, and if the availability of such channels, potentially improving information exchange, are a relevant selection criterion for companies when selecting suppliers. Thus, we pose the following research question, specifically addressing issues of information exchange (through digital channels) as well as sustainability performance: (1) "Which performance indicators do companies assess in suppliers, and what is the relative importance of sustainability-related and digitalization-related performance in suppliers?", and further specify the following sub-questions:

Which criteria do companies prioritize in the selection of suppliers?
How relevant is the general willingness to exchange data for supplier selection, and how relevant are digital interfaces for data exchange?
Which sustainability-related performance indicators are considered during supplier selection, and what is their relative importance?

2.2. Boundary conditions of supplier sustainability assessment

Not only in the electronics industry is there a conceivable pressure to adopt international standards of SSCM and share information on such efforts with supply chain partners (Mol, 2015; Sturgeon and Kawakami, 2011; de Marchi and Maria, , 2019). However, it is questionable as to what constitutes a company's boundary conditions that frame both processes of collecting and sharing information for sustainability assessments. To categorize boundary conditions, we included four of the levels of focus described by Walker et al. (Walker et al., 2012) to evaluate sustainability in the context of supplier management: "organizational", "buyer–supplier dyad", "supply chain / network" and "society / stakeholders".

Concerning the organizational level, varying aspects of company characteristics have been discussed to influence supplier sustainability assessment and subsequent information sharing. For instance, financial constraints are popularly mentioned as an important barrier for the implementation of SSCM (Govindan et al., 2014). This is especially true for small- and medium enterprises (SMEs) (Foerstl et al., 2015). On the other hand, the availability of certain firm capabilities, such as a good understanding of issue-specific measurement methods is positively associated with supplier sustainability assessments (Gualandris et al., 2015). Moreover, cost of adequate information technology is a restricting factor (Lotfi et al., 2013), posing challenges for (i.a.) life cycle management of products (Wang et al., 2016).

With regards to the level of "buyer-suppler dyad", multiple facets of this relationship are argued to influence supplier sustainability assessment. Difficulty to obtain desired data in supply chains (Genovese et al., 2017) and thus extract relevant information can be attributed to a lack of willingness to share data. This may be the case because keeping information within company boundaries is sometimes perceived as retaining a competitive advantage (Egels-Zandén et al., 2015). Conversely, trust between supply chain partners has been shown to foster information exchange (Jira and Toffel, 2013). Brun et al. (Brun et al., 2020) show that trust impacts supply chain visibility, which is positively associated with supply chain sustainability and transparency. More specifically, the sharing of production data (e.g. scrap rate) between supply chain partners is positively associated with trust and benefit sharing (Müller et al., 2020). In the context of social sustainability practice implementation, it has also been mentioned that increasing pressure of buying firms on suppliers needs to be accompanied by the establishment of long-term trustworthy relationships (Govindan et al., 2021). Moreover, the importance of having a shared vision between organizations as well as relation-ship specific investments has been shown to promote inter-organizational information sharing (Jira and Toffel, 2013). Also, suppliers are more likely to share sustainability-related information when requested by multiple buying firms, and when buying firms appear committed to using this information (Jira and Toffel, 2013).

The level of "supply chain / network" implies an understanding of the impacts of GSCs on sustainability assessments in a broader sense, focusing on industry-specific characteristics. For instance, suppliers are more inclined to share such information when they are situated in a profitable industry (Jira and Toffel, 2013). Moreover, especially in the electronics industry, collaboration of global buying firms and major suppliers aims towards standardization of sustainability requirements and thus related information exchange (Wilhelm and Villena, 2021). In contrast, the heterogeneity of supplier sustainability assessment approaches, embodied in the variety of codes of conduct, has been reviewed skeptically (Schleper and Busse, 2013). A lack of consistency in assessment practices is associated with engagement in auditing fraud (Lund-Thomsen and Lindgreen, 2014) and it creates operational difficulties and additional procedural costs (Schleper and Busse, 2013). Likewise, a lack of industry-wide (or even global) data sharing protocols are argued to hamper effective inter-organizational information exchange (Luthra and Mangla, 2018). Although information unavailability is often perceived as a major obstacle for SSCM (Sharfman et al., 2009), opposing effects may also negatively impact SSCM. That is, massive amounts of data from a variety of supply chain partners can result in information overloads (Montecchi et al., 2019). Companies may have the means to acquire relevant data, but they struggle to transform this data to support decision-making and thus transparency (Morgan et al., 2018). In conclusion, companies must aim to find a fit between their information processing needs and their internal information processing capacity (Busse et al., 2017).

Concerning the level of "society / stakeholders" external pressure from both policy makers as well as specific stakeholder groups have been investigated. Foerstl et al. (Foerstl et al., 2015) hold that stakeholder pressure is the principal driver of sustainability efforts. Moreover, Ghadimi et al. (Ghadimi et al., 2016) emphasize the lack of effective legislation as a major barrier for sustainability assessments. Additionally, Wilhelm & Villena (Wilhelm and Villena, 2021) show that adoption of sustainable procurement practices is positively influenced by the engagement with key stakeholder networks of the focal

firm. Also, customer pressure has been stated as driving the implementation of sustainable procurement (Ghadge et al., 2019). Regarding compliance with legal norms and policies, doubt has been expressed by some authors as to whether reliance on policy makers to incentivize or enforce SSCM practices will foster improvements in all areas of sustainability, let alone all countries (Clarke and Boersma, 2017). The degree of legislative governance in (not only) many developing countries regarding SSCM has been described as low (Bae et al., 2018).

Following the uncertainty surrounding the process of supplier sustainability assessment, we aim to answer the following research question:

(2) What are the main boundary conditions framing the process of supplier sustainability assessments in the electronics industry?

2.3. Digital solutions for supplier sustainability assessment and monitoring

As outlined in chapter 2.1, companies appear to employ a rather narrow set of measures and tools to assess their suppliers' sustainability performance, most frequently relying on self-assessment questionnaires for data collection (Lee and Kashmanian, 2013) and in-person audits as a means to verify the validity of these claims (Fraser et al., 2020a). Yet, digital technologies provide various opportunities to improve both data availability and verifiability of sustainability claims. The burgeoning debate around Industry 4.0 has portrayed a variety of ways through which digital technologies may impact the sustainability of companies and thus of supply chains (Bai et al., 2020; Ghobakhloo, 2020). Nevertheless, a broadly shared definition has been lacking (Beier et al., 2020). In this study, we adopt a narrower perspective, focusing on digital solutions to facilitate the collection, inter-organizational sharing and analysis of sustainability-related information to improve supplier sustainability assessment. In this sense, we concur with the findings of (Ebinger and Omondi, 2020; Bag et al., 2018) that the notion of Industry 4.0 includes multifaceted technological approaches to improve SSCM based on real-time information. Regarding data collection, underlying technologies such as wireless sensors equipped to physical objects, also known as the IoT (Yang, 2014) enable data collection on products and production processes. Similarly, establishing interconnections to create CPS enables the seamless integration of and communication between physical entities (Klötzer and Pflaum, 2015; Beier et al., 2018). With regards to both intra- and inter-organizational data storage and exchange, cloud computing provides digital platforms which facilitate scalable solutions for heterogeneous data coming from multiple sources (Durao et al., 2014). Transforming the increasing amount of data into actionable knowledge, BDA offers descriptive, predictive and prescriptive solutions to promote decision-making (Liu et al., 2020). The various functions of digital technologies are rarely discussed in isolation in the context of Industry 4.0, but rather viewed in conjunction, highlighting their potentially transformative impact on industrial production (Beier et al., 2020). Nevertheless, recent findings on specific use cases of digital solutions are provided in the following paragraphs in order to delineate the suggested potential for the improvement of supplier sustainability assessment.

With regards to the collection of data, enabling technologies of Industry 4.0 such as radio-frequency identification (RFID) facilitate the collection of sustainability-related data at different stages in the supply chain, such as carbon emissions in logistics and the recyclability or reusability of discarded products (Rane and Thakker, 2019). Inside production facilities, machine generated data enables real-time monitoring of energy consumption of production as a foundation for energy efficiency assessments (Shrouf and Miragliotta, 2015; de Sousa Jabbour et al., 2018; Ren et al., 2019).

Regarding data exchange along the supply chain, prior research has investigated the utilization of cloud-based platforms for SSCM and supplier sustainability management. Taghaboni-Dutta et al. (Taghaboni-Dutta et al., 2010) developed an XML-based platform that can be used in supply chains for the exchange of environmental data of products regarding material composition. Similarly, Xing et al. (Xing et al., 2016) develop a cloud-based LCA platform, enabling the collection and exchange of life cycle data between supply chain partners for environmental footprint assessments, illustrating its feasibility in the fashion industry. Furthermore, Ebinger & Omondi (Ebinger and Omondi, 2020) illustrate approaches in different industries to establish cloud-based platforms on which participants can store and exchange information related to supplier sustainability assessments, such as supplier self-assessments, auditing and monitoring results. Alternatively, existing enterprise resource planning (ERP) systems can be extended to facilitate the sharing of data of sustainability information systems (Meacham et al., 2013). However, a lack of interoperability has been shown to be a common issue, inhibiting comparability of exchanged data and hence further processing (Agostinho et al., 2016). In recent years, blockchain-based solutions have also been discussed in the context of SSCM, providing means for both data exchange and data validity assurance. Blockchain solutions enable decentralized data storage in which network participants directly interact with each other, examining the validity of data and information stored in "blocks" based on consensus rules in order to confine data misuse and manipulation (Kouhizadeh and Sarkis, 2018). Blockchain, coupled with other Industry 4.0 solutions, can be used to track the sustainability performance of suppliers (Rane and Thakker, 2019). Francisco & Swanson (Francisco and Swanson, 2018) develop a conceptual model for the use of blockchain to achieve supply chain transparency, highlighting its potential for the assessment of supplier sustainability compliance. Furthermore, de Sousa Jabbour et al. (de Sousa Jabbour et al., 2018) propose the utilization of blockchain to trace product carbon footprints along supply chains.

Regarding the analysis of increasing amounts of heterogeneous data in the supply chain, various studies have investigated the application of BDA in the context of SSCM (Liu et al., 2020; Ren et al., 2019). Prior research has indicated great potential of BDA for life cycle assessments (LCA), even though the current implementation of such approaches is low (Beier et al., 2022). Moreover, BDA-based approaches have been developed to assist the supplier selection process, enabling the consideration of sustainability-related indicators. For instance, Singh et al. (Singh et al., 2018) provide a framework to measure carbon emissions as a criterion for supplier selection in the agricultural industry. BDA also offers opportunities for predictive analyses in the context of SSCM. Shabanpour et al. (Shabanpour et al., 2017) utilize artificial neural networks to forecast sustainability-related supplier performance.

The role of digital solutions for SSCM is not only of scientific concern. In recent years, a variety of industry initiatives began to harness digital solutions for more sustainable GSCs and service providers emerged or expanded their business, offering an increasing amount of tools to tackle issues related to supplier sustainability assessment. For instance, the Responsible Business Alliance (RBA), a non-profit organization originating from the electronics industry which is committed to fostering more sustainable GSCs, offers data management systems to facilitate sharing of sustainability data such as audits and self-assessment questionnaires among supply chain actors. Likewise, the Global enabling Sustainability Initiative (GeSI) aims to harness digital solutions for sustainable supply chains. Their "E-Tasc" tool sets the goal to implement a common approach for assessing and monitoring suppliers' sustainability practices, including the categories of labor, ethics, health & safety, and environment. It allows for an easy management of self-assessment and audit data. Moreover, established and international companies developing ERP software also provide compatible solutions for an integrated supplier management, harmonizing data management on basic functions (e.g. transactional, contractual) with sustainability functions to enable centralized data management.

Also, prototypes of innovative solutions are explored by a variety of actors. “SustainBlock” is a blockchain-based project to demonstrate the presence of small-scale mining sites to provide downstream companies with information on the provenance materials and ensure that products be of conflict-free materials.

In conclusion, the surge in the interest in the role of digital technologies for SCM (Kache and Seuring, 2017) is starting to also gain traction in SSCM. However, research at the interface of SSCM and Industry 4.0 is still scarce (Manavalan and Jayakrishna, 2019), especially with regards to empirical insights. On a more general level, it is even more surprising that research has paid very little attention to the empirical investigation of the “how to?” of supplier sustainability assessment (Fraser et al., 2020b). Thus, we pose the following question: (3) “What are current practices in supplier sustainability assessment, and what role do digital technologies play now and in the future?”, specifying the following sub-questions:

(3.1) What are currently established practices for the supplier sustainability assessment? How are digital technologies relevant for these practices?

(3.2) How do practitioners perceive the future role of digital technologies for supplier sustainability assessments?

3. Methodology

3.1. Conceptualization of the research approach

Following the summary of interlinkages between supplier sustainability assessment, its boundary conditions, and Industry 4.0, we briefly outline our research approach which builds on the cited literature and research gaps mentioned.

Firstly, research and current industrial practices show that companies aim to evaluate suppliers for a broad spectrum of criteria for which relevant information may be lacking, including social and environmental performance (Foerstl et al., 2018). However, there is a dearth of evidence regarding the relative importance of supplier selection and assessment criteria and it remains an open question if companies take into consideration a supplier’s ability to share information digitally as a valuable criterion to overcome limited transparency. Hence, we aim to investigate the different criteria assessed and weighed in supplier (sustainability) assessment (RQ 1). Secondly, different factors have been implied to have an impact on the degree to which companies perform sustainability assessments and share resulting information with supply chain partners. Covering “organizational”, “buyer–supplier dyad”, “supply chain / network” and “society / stakeholders” factors, prior research highlights the context dependency of such factors (Walker et al., 2012), requiring investigation of their interplay in specific settings. Consequently, our goal is to provide exploratory insights from the electronics industry (RQ 2). Thirdly, the extant literature has largely neglected an investigation of the standardized tools used for supplier sustainability assessment (Fraser et al., 2020b), let alone context-specific solutions. Moreover, even though Industry 4.0 is argued to improve SSCM and contribute to corporate sustainability, empirical evidence of corporate practices and the sustainability-related impacts remain scarce (Beier et al., 2020). Thus, we aim to investigate a specific use case for the potential feasibility of digital solutions for sustainability, focusing on supplier sustainability assessment (RQ 3).

Although we acknowledge the relevance of assessing all actors in a supply chain in terms of sustainability and encourage the promotion of multi-tier SSCM (Fraser et al., 2020c), we focus on the dyadic relationship between buying firms and first-tier suppliers. We view this as a fruitful approach due to the impression that supplier sustainability assessments are usually conducted on a bilateral basis and because of the low degree of supply chain wide exchange of non-mandatory sustainability-related information (Schöggl et al., 2016). In this sense, data collection by first-tier suppliers includes their investigation of second-tier suppliers’ sustainability performance. Including first-tier suppliers’ perspectives in both directions in terms of supply chain partners may yield relevant insights concerning cascading of assessment practices in the supply chain (Dahlmann and Roehrich, 2019), emphasizing their double agency role to both fulfil buying firms’ requirements and implement them further down the supply chain (Wilhelm et al., 2016). Additionally, even though economic sectors are increasingly intertwined (Bustinza et al., 2017), we focus on the manufacturing sector in the electronics industry, i.e. supply chain actors who are

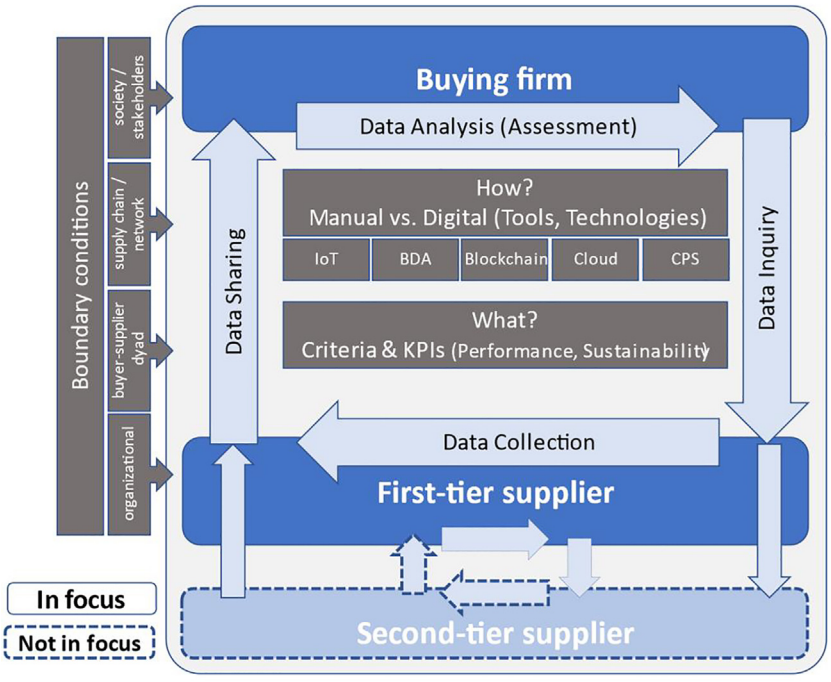

Fig. 1. Boundary conditions and digital solutions for supplier sustainability assessment.

involved in the production of a final product and not only of services due to the differences in the supply chain activities of service providers and producers. We visualize the integration of our research questions in Fig. 1.

3.2. Expert interviews

Given the exploratory nature of our study, we chose to conduct qualitative, guideline-based expert interviews in the electronics industry. We performed a pre-test of the guideline in July 2020 through an interview with an industry representative and expert in the field, after which minor adjustments were made to the initial guideline. In addition, an internal revision among colleagues with relevant scientific expertise but no association with our study further established validity of the employed interview guideline. We also consulted thematically and methodologically linked prior studies, such as (Beier et al., 2022); to ensure construct validity (Busse et al., 2016).

To provide a comprehensive assessment of our research object and to account for the variety of perspectives relevant to our research questions, we aimed to incorporate the knowledge and experience of both "buying firms" and "suppliers". This is in line with the notion that the investigation of supply chain sustainability requires knowledge of inter-organizational issues that actors at different stages in the supply chain hold (Seuring and Gold, 2013). Given the inherently inter-organizational character of information exchange in supply chains, this let us capture different perspectives on the phenomenon (Egels-Zandén et al., 2015), while also limiting bias (Eisenhardt and Graebner, 2007). To delineate the two groups of "buying firms" and "suppliers", we define buying firms as those who sell a final product, for instance under a specific brand. Such buying firms are also recognized as "lead firms" or "focal firms" (Grimm et al., 2016), reflecting their central position in the supply chain. Secondly, we define suppliers as first-tier suppliers, i.e. those firms who have direct business relationships to buying firms. Due to the complexity of many supply chains and the variety of functions a single company may fulfil – even with a single business partner – we emphasize our focus on their specific role in the context of our study in accordance with the interview guideline. Thus, interviewees among the group of "suppliers" are not necessarily supplying the interviewed "buying firms" as we did not inquire about potential business relationships among study participants due to reasons of discretion.

We conducted a total of 10 interviews among the group of "buying firms" between July and November 2020. Interviews lasted between 41 and 101 min. Due to the Corona pandemic, we used online conferencing software to conduct the interviews. The interview guideline can be divided into three sections. In the first (introductory) section, we asked questions addressing general characteristics of the interviewees and their company's supply chain characteristics (e.g. number of suppliers). In the second section, we asked questions about criteria of supplier selection, means of data collection and assessment, and modes of communication with suppliers. In the third section, we asked more broadly about the current and envisioned use of digital technologies for sustainability-related goals in supply chain management. Moreover, the guideline included a quantitative assessment regarding the importance of criteria evaluated in supplier selection. That is, we asked interviewees to rate the importance of a set of criteria, ranging from 1 ("not important at all") to 10 ("very important"). The complete interview guidelines for buying firms and suppliers are attached in appendices A and B. Different approaches were used to identify potentially suitable interviewees for both buying firms and suppliers. Besides desk research on individual companies, we contacted ten associations and corporate networks as well as six civil society organizations to inquire about their members' interest in participating in our study. In total, 68 companies were contacted. We initially contacted company representatives both by email and telephone to introduce the study's background and goals. Besides affiliation with the targeted industry, we limited our search to professionals who work in departments related to SSCM. SSCM is connected to different corporate functions and departments, including procurement, production and sustainability (Busse et al., 2017). This is also reflected in the positions of interviewees from buying firms, who held positions such as "Supply Chain Manager", "Supplier Sustainability Director", or "Procurement Manager". The status of "expert" in the topics of our interviews was not assessed externally, but instead by perception of the interviewees to have sufficient and profound knowledge of the questions conveyed in our introductory communication. In that sense, the status of being an expert is assigned to people in a specific function or role (Kaiser, 2014) – in our case professionals in supply chain management – who through their expertise and knowledge regarding a specific phenomenon, are able to contribute to a better understanding of the research object (Gläser et al., 2010).

Regarding the group of "suppliers" we slightly adapted data collection. Firstly, we restricted our search for interviewees among this group to suppliers in the electronics industry which are based in mainland China, due to the role that China plays especially in providing intermediate goods in the electronics industry (Raj-Reichert, 2018). Secondly; we chose to collect written responses only and to avoid language barriers, we translated the interview guideline into Mandarin. This translation was checked by a native speaker and expert in the field. Minor adjustments to the guideline were made to allow for replies from the perspective of suppliers. Contact initiation and inquiry of the expert status are similar to the interviews among the group of "buying firms". Replies were re-translated into English. A total of 8 replies from supplying firms were collected between November 2020 and February 2021. Interviewees of suppliers held similar positions as interviewees of buying firms, such as "Head of Supply Chain" or "General Manager", however, no interviewed supplier was specifically associated with the respective company's sustainability department.

We have summarized key characteristics of buying firms and suppliers, as provided during the interviews, in Table 1 and Table 2 respectively. In the following, we will refer to interviewees by their assigned codes according to the respective table ("B" = "buying firm", "S" = "supplier").

The electronics industry presents multiple characteristics that made it appealing and suitable for our investigation. In recent years, the electronics industry has undergone some noteworthy changes, especially regarding the interplay of buying firms and suppliers. Not only is there increased competition among buying firms, but also have first-tier suppliers increasingly widened their capabilities and cemented their position in the electronics GSC (Raj-Reichert, 2018). The electronics industry is also closely connected with other industry sectors such as the ICT industry, which has been investigated for its high output volume and the high degree of fragmentation in GSCs (Sturgeon and Zylberberg, 2016). That is, modularization of product architecture gave rise to the global standing of the electronics industry (Butollo, 2021), establishing close connections to various other industries that increasingly rely on inputs from the electronics industry. Also, companies in the electronics industry have received broad media attention because of sustainability-related scandals, not least at first-tier suppliers, as evidenced by the case of Foxconn (Ngai and Chan, 2012). However, at the same time, companies praise their sustainability initiatives and endeavors to "go green" by relying on renewable energies for instance (Beier et al., 2020), demanding further investigation of current practices. Moreover, prior studies investigating digital solutions for SSCM have largely concentrated on few sectors, such as the agroindustry (e.g. (Allaoui et al., 2019), calling for a diversification of empirical investigations.

3.3. Qualitative content analysis

After data collection, we used MAXQDA to transcribe recorded interviews of buying firms to have responses in written form by all

Table 1
Interviewed buying firms.

Interviewee (Position)	Size (Employees in 1,000)	No. of suppliers	Location of suppliers	Sub-sector/product type
B1 (Director Advanced Manufacturing)	100–500	~ 30,000	Global distribution (~60 countries)	Multimedia, Automotive electronics
B2 (Smart Logistics Manager)	100–500	"Ten thousands"	Global distribution (~300 production locations concentrated in Europe, Asia (China), North America	Smart home & household appliances
B3 (Supply Chain Manager)	0.1–0.5	~25	Across Europe, China	Consumer electronics peripherals
B4 (Director Supply Chain Management)	1–10		Concentrated in Germany; China, Romania, US, Mexico.	Electrical connectors
B5 (Director Supplier Sustainability)	50–100	~4500	Clusters in Asia (China), North America, Europe	Household appliances, multimedia
B6 (Procurement Manager)	100–500	Unspecified	Unspecified	Household appliances
B7 (Supply Chain Manager)	1–5	Unspecified	Concentrated in China, significantly smaller clusters in India, Vietnam	Telecommunication equipment
B8 (Procurement & Manufacturing Manager)	0.1–0.5	100–150	Concentrated in Germany, smaller clusters in China	Data center equipment
B9 (Business Development Manager)		50–100	Concentrated in Germany, rest of Europe	Smart sensors
B10 (Sustainable Sourcing Manager)	100–500	>20,000	Concentrated in Asia	Multimedia, mobile phone

Table 2
Interviewed suppliers.

Interviewee (Position)	Production location	No. and location of customers (buying firms)	No. and location of 2nd tier suppliers	Sub-sector/product type
S1 (Supply Chain Manager)	Shanghai	~3,000 – 4,000 customers, largely SMEs and few brand companies. High concentration in China, Taiwan, Hong Kong, few customers in Japan and the EU.	~50 suppliers, mainly from Europe, US, Japan, Taiwan, China	Unspecified intermediate components
S2 (Production Director)	Suzhou	Unspecified customer base and location	Unspecified (large) and global supply base, concentrated in China	Laptops
S3 (Procurement Manager)	Nanjing	~600 customers, mainly located in Europe, America, and Southeast Asia	~320 suppliers, unspecified distribution	Household appliances
S4 (Production & Planning Manager)	Shenyang	~70 customers, largely located in China, Latin America	~100 suppliers, largely located in China, Europe, US	Smart measurement tools
S5 (Supply Chain Director)	Shanghai	Unspecified customer base, concentration in China	~100 suppliers, highly concentrated in China	Household appliances
S6 (Production Manager)	Guangdong	~200 customers, concentrated in SE Asia, India, the Middle East, North America, China	~200 suppliers, concentrated in China, Japan, South Korea, US, Germany	Air conditioner
S7 (CEO)	Shenzhen	~ Customers, all located in China	~100 suppliers, concentrated in China	Unspecified intermediate components
S8 (Production Line Development Manager)	Taizhou	~40 customers, highly concentrated in China	~10 suppliers, all located in China	Unspecified intermediate components

interviewees. The same software was used to perform qualitative content analysis of the interviews. The purpose of qualitative content analysis is to attain a description of a phenomenon using categories to describe it (Elo and Kyngäs, 2008). We followed the approach of content-structuring content analysis (Schreier, 2015) and proceeded with the following steps. Firstly, main categories were established deductively from the interview guideline. Secondly, text passages relevant to our research questions were coded and assigned subcategories inductively, which were then grouped to the main categories. We also followed the guidelines of Saldana (Saldana, 2021) for collaborative coding. Two researchers were engaged in the data analysis process and first independently assigned sub-categories. After a first round of coding, the assigned categories between the two researchers were compared. Consensus had to be reached to keep a specific category, otherwise a new iteration followed. To improve consistency of the category system, appropriateness of the assigned category for all coded text passages was checked again. During this process, modifications were made if required, for instance by merging similar sub-categories. A high degree of agreement among researchers was also necessary to ensure reliability of the coding process and the following data analysis (Crum et al., 2011).

4. Results

The presentation of results is structured in accordance with the research questions we pose.

4.1. Criteria assessed in the selection of suppliers, role of digitalization, and relevance of supplier sustainability assessment (RQ 1)

4.1.1. Dominant role of traditional key performance indicators (KPIs) (RQ 1.1)

When asked about the criteria according to which buying firms assess potential suppliers, they highlight that a combination of aspects be taken into consideration and weighted with regard to the purpose of the business relation (B6). Mentioned criteria range from price, credit history, to production capacity, performance of second-tier suppliers, lead time, among others (B1, B2, B3, B6, B10). Furthermore, we asked suppliers about the criteria applied for their supplier selection (i.e. second-tier suppliers) and found similar responses that highlight the importance of traditional key performance indicators, such as lead time, production volume or product quality (S2, S3, S6).

We have asked buying firms to rate the importance of specific criteria for supplier selection on a scale from 1 ("not important at all") to 10 ("very important"). To complement buying firms' perceptions, we asked suppliers to provide estimations as to what they think are the most valued criteria of buying firms, i.e. their perception of the relevance of criteria according to which they (suppliers) are being evaluated. The results are summarized in Table 3. Perhaps unsurprisingly, quality (of products) seems to be the most valued aspect of buying firms in suppliers. As one buying firm states, maintaining the highest of standards for product quality is essential to be successful in the market over a long period of time (B7). Consideration of recommendations about suppliers was rated the least relevant criterion for supplier selection by buying firms.

Table 3
Supplier selection criteria.

Supplier selection criteria	Buyers' perspective	Suppliers' perspective*
Quality	9.8	8.9
Adherence to delivery dates	8.9	8.4
Transparency	8.5	7.0
Price	8.2	8.4
Willingness to exchange data	8.1	5.4
Data availability	7.9	6.8
Digital equipment and digital know-how	6.8	6.4
Recommendation from another firm	5.4	5.4

* The suppliers' perspective describes their perception of the relevance of criteria according to which they (suppliers) are being evaluated

4.1.2. Criteria related to digitalization (RQ 1.2)

Given our interest in the role of digital technologies in SSCM, interviewees were asked to report about their perceived importance of topically related criteria for supplier selection, such as data availability, digital equipment and digital know-how, and willingness to exchange data. Some buying firms state that a certain degree of digitalization of data exchange with suppliers is a prerequisite, as well as the existence of compatible digital interfaces between buyers and suppliers. As one buying firm with thousands of suppliers states, *"this is a must (…). If we cannot communicate on a digital level and the interfaces are incompatible (…) then it's difficult for us to select such a partner"* (B1). Another similarly large buying firm shares their belief that the proliferation of digital technologies in suppliers improves their performance in other relevant areas, such as transparency and quality (B2). Moreover, an interviewed buying firm with a geographically clustered and smaller supplier base reports about bad experiences with microenterprises as suppliers who rely on manual data exchange, referring to the relevance of software-based solutions for product quality assurance and delivery timelines (B8). In contrast, other buying firms do not value digitalization in suppliers much per se, as long as other criteria are met. B9, having fewer than 100 suppliers, states that *"if the product is very good, at the end of the day, I don't care about their digital equipment"* (B9). Likewise, another global player with a broader product range expresses that *"if they can do it digitally, or if they can do it manually, it doesn't really matter as long as it's good quality and good price"* (B10).

Buying firms do expect a certain willingness to exchange data and value transparency, but they differ in the quality of their demands and wishes regarding data availability and exchange. As B2 states, *"in general, transparency is, of course, very important for trustful collaboration in the supply chain"* (B2). There should be no reason for suppliers to hide if they are "able and good" (B1). In some cases, buying firms hope for higher levels of data exchange than what suppliers currently provide: *"I would like to know everything about suppliers (…) and I would like to have all the data. However, that is like Christmas and birthday at once"* (B6). Especially interviewees with a smaller supplier base highlight that, although a supplier's willingness to exchange data is important, data availability is only necessary and valued to a certain degree, as it has to be reasonable, practicable and useful (B7, B8). Generally, willingness to exchange data can become more important under specific circumstances, e.g. when perceptions between buyers and suppliers regarding reasons for issues differ. As one interviewee states, *"it is important that I can, so to speak, sound somebody out if they have a problem and they think it's not too bad"* (B9).

4.1.3. Supplier sustainability assessment (RQ 1.3)

We specifically asked about the relevance of sustainability-related criteria concerning social and environmental performance of suppliers for their selection. Only one interviewee did not know if sustainability-related criteria are taken into consideration during the supplier selection process (B2). Although few interviewees mentioned sustainability-related criteria of their own accord, a variety of criteria were expressed as relevant once we asked specifically about it. As one buying firm that sources globally from thousands of suppliers comments, *"we talk to them about labor conditions, about the salaries that they offer, about the overtime that they expect, about their environmental performance, (if they have) programs to reduce their carbon emissions, are they looking to effectively re-use their waste, or at least not send it to landfill, do they provide a workplace that is sufficiently safe"* (B5). B10 similarly remarks that suppliers are selected under consideration of a multitude

of criteria related to environmental performance, compliance with human rights and working safety standards (B10). Multiple interviewees stress the importance to assess suppliers' compliance with legal norms regarding environmental and/or social regulations. Whereas some stress the importance to assess potential breaches of labor laws, e.g. child labor or forced labor (B4, B6), others underscore compliance with regulations regarding environmental standards, e.g. use of hazardous substances (B8, B9). However, there are also cases in which the assessment of sustainability-related criteria in supplier selection goes beyond compliance with legal norms towards meeting firm specific codes of conduct. (B5, B6, B10). Interviewees convey the impression that there are differences in the relative importance of sustainability-related criteria, which may lead to different outcomes in supplier selection. B3, sourcing from only 25 suppliers, states that their company takes great responsibility in maintaining high labor standards in suppliers, but that environmental friendliness of production at suppliers' facilities is not a criterion that leads to the exclusion of potential suppliers (B3). Another interviewee states that *"if we find that there are human rights issues in the supply chain and they don't answer, refuse to give us an answer, then we can't work with them. But then, if we want to have climate data and they're not willing to give it to us and this is something very new, then it's not"* (B10), i.e. not a reason to exclude potential suppliers from the selection process.

There is a great discrepancy in suppliers' responses when asked about their reporting of sustainability-related criteria to buying firms. Multiple interviewees report that they are not required by buying firms to provide data on sustainability-related criteria (S1, S3, S4, S7, S8). As one supplier distributing to Europe, America and Asia states, *"At present, there is no requirement to provide [data on] environmental or social indicators"* (S3). Among those, one company states that even though they are not required to do so, they still provide their emission reduction reports and energy conservation plans to buying firms (S1). Suppliers who do provide data on sustainability-related criteria express a similarly broad range of aspects as the ones required by interviewed buying firms. They report that they are being requested to provide data on environmental issues such as energy consumption (S2, S6) and the existence of environmental management systems (S5), but also about occupational safety (S2, S5, S6) and employee rights (S6).

Suppliers were also asked to report if sustainability-related criteria played a role in the selection of their suppliers (second-tier suppliers). Among the suppliers who are not required to report on these criteria to buying firms, only one interviewee mentioned that they request their suppliers to provide information on the operation of environmental management systems (S3). Another supplier mentions their goal to improve transparency regarding the environmental impact of their products as a reason to request relevant data from second-tier suppliers. (S5). Moreover, another supplier explains that the type of data requested from second-tier suppliers regarding sustainability-related criteria partially "depends on the needs of upstream and downstream enterprises" (S2), alluding to pressure from buying firms to pass on their data demands down the supply chain.

4.2. Factors influencing supplier sustainability assessment (RQ 2)

4.2.1. Supply chain complexity

The interviewees report a variety of factors framing supplier sustainability assessment (see Table 4). One recurring topic is linked to the complexity of the supply chain. Some of the interviewed buying firms have very large supplier bases, which poses difficulties to thoroughly assess suppliers. Hence, although a buying firm may generally aim to assess a spectrum of sustainability-related criteria in suppliers, the entirety of criteria might not be considered for every potential supplier. Instead, the importance of the respective relationship is gauged, for instance in terms of share of procurement spend, regarding the perceived risk of non-compliance of suppliers, or according to the perceived performance of suppliers concerning specific criteria. An example is provided by one buying firm with a global supplier network which explains how they proceed in assessing suppliers' carbon emissions: *"If you look at the code of conduct, that is something that we have with all of our suppliers. If you look at us requesting them to start reporting on the carbon emissions, we do that with about 25% of our total supply base, the ones that we think are the most carbon intense"* (B5). Another buying firm stresses the risk approach to specify the range of sustainability-related criteria being assessed: *"We do that on our high-risk suppliers (…) when we see something we want to specifically investigate, or any kind of new supplier, that we want to look at"* (B10).

Suppliers also mentioned the restructuring and growth of supply chains as factors influencing the assessment of sustainability-related criteria (S8). One supplier with relationships to buying firms in North America and Asia reports that previously, the *"supply chain was relatively stable, and there were few requirements for environmental, social or sustainable development indicators"* (S4), but that increasing multi-sourcing as well as diversification of production will pose higher challenges for the assessment of sustainability-related criteria in suppliers. Likewise, another supplier argues that "the current supply chain feels ever-changing and is subject to change at any time due to certain

Table 4
Boundary conditions framing supplier sustainability assessment.

Boundary conditions	Buying firms	Suppliers
Society/Stakeholders	• Questioning responsibility for voluntary assessments (B6) • Awareness for legislative changes on different levels (national, international) (B5) • Call for framework ensuring equal requirements towards companies (B5)	• Focus on domestic changes to the legal framework (S1)
Supply Chain/Network	• Heterogeneity of data requirements for similar voluntary assessment criteria (B10)	• Trend towards multi-sourcing and diversification increases amount of SC partners and information sharing requirements (S4, S5, S8)
Buyer-Supplier Dyad	• Reluctance of suppliers to share sustainability information when no direct advantage is perceived (B8, B9) • Inability to validate supplier data requires trustful relationships (B6, B7)	• Lack of specification of requirements from buying firms (S4) • Unavailability of publicly disclosed data to assess second-tier suppliers (S1) • Non-disclosure of second-tier suppliers to retain competitive advantage (S6) • Enforcement of information provision from second-tier suppliers due to powerful SC position (S2)
Organizational	• Supplier base size requires careful allocation of resources and prioritization of assessed actors, criteria assessed and of tools used (B5, B10)	• Unfamiliarity with assessment criteria (S5) • Limited resources to validate claims of second-tier suppliers (S4)

unforeseen circumstances" (S5), which increases the requirements for related data analysis.

4.2.2. Standardization of data requirements

We also encountered opinions among buying firms and suppliers which highlight standardization of data requirements for sustainability indicators as an issue. Specifically, a lack of standardization is seen as problematic. One buying firm states that suppliers' familiarity with data requirements is less of an issue for standardized criteria, such as those referring to legal standards (B10). However, since buying firms may have different standards for voluntary indicators, suppliers are often overwhelmed by complexity, because they lack the experience or because they face different reporting requirements from different buyers regarding a similar indicator: *"if you're working with climate and the problem that every customer has different requirements. So, they come to an organization either the organization, or the supplier, has never been approached, because it's a kind of a new topic. Second, it's being approached with several different types of requirements (…) So, those are two things. They're not used to answering questions and the question is fuzzy"* (B10). This is also reflected in one supplier's statements, emphasizing unfamiliarity with data requirements even when selling and buying domestically: *"Well, sometimes you are not familiar with some indicators, and you need to understand the meaning of the indicators"* (S5). In another case, even if the supplier is familiar with the subject, they are unable to report as requested, because the brand company *"did not set thresholds for these indicators"* (S4), i.e. data requirements are not specified.

4.2.3. Legal norms as impetus

Responses regarding the types of sustainability-related data collected already imply motivating factors of their collection. As such, developments in laws and regulations are mentioned as an important impetus. One buying firm with global visibility for a broad range of electronic household appliances raises the question whether companies or policy makers have greater societal responsibility to foster sustainability assessments of suppliers: *"The question is, if a company has this role in society, to guarantee this, or if this is a legislative issue"* (B6). One interviewee mentions that it is necessary for buying firms to be aware of potential changes in legislation in suppliers' jurisdictions: *"I think China for instance announced that they are going to become carbon neutral (…) That is something that should be taken seriously by our companies that manufacture there. Because the government will take steps and enforce that regulation. And the same goes for Europe, of course"* (B5). The same interviewee underscores the importance to enforce accountability of all companies for the societal burden that is associated with the socially and environmentally detrimental effects of activities along the supply chain (B5). Suppliers emphasize the role of regulation in a similar fashion, especially regarding carbon emission reporting (S4, S8). As one supplier with both global sourcing and distribution states, *"as the construction of China's domestic carbon emissions trading market advances, we may require suppliers to provide information on product carbon emissions"* (S1).

4.2.4. Willingness to exchange data and ability to verify data

Lastly, buying firms and suppliers highlight the willingness to exchange data as well as the ability to verify data as factors influencing the assessment of sustainability-related criteria in suppliers. Although we have shown that not all buying firms demand absolute data availability on all potentially relevant criteria for suppliers, a lack of willingness to exchange data is, by some, perceived to hamper supplier sustainability assessment. One buying firm mentions that suppliers are generally wary to exchange data if they do not see how they benefit from the exchange, or worse, if it can potentially be used against them (B9), as is the case with sustainability-related data. Hence, fostering a greater willingness to exchange data through relationship management with suppliers is viewed as a challenge (B8). With regards to verification of data coming from suppliers, one buying firm mentions that it has encountered numerous instances in which suppliers deliberately provided misinformation regarding sustainability-related criteria. As they admit, they largely rely on what the suppliers tell them (B6). Similarly, another interviewee mentions that they oblige suppliers to comply with their code of conduct, *"but in reality, there is nothing more we can do, quite frankly"* (B7). Suppliers mirror some of these statements when asked about their sustainability assessment of second-tier suppliers. Second-tier suppliers are reluctant to share relevant data and *"it is sometimes difficult for us to collect supplier information through open online channels"* (S1). Others mention that suppliers are unwilling to report on specific indicators, such as product-related energy consumption, because they fear competitive disadvantages if disclosed (S6). However, willingness to exchange data also depends on the positioning in the supply chain, as one supplier that largely sources domestically in China but supplies global buying firms reports that power relations enable them to collect necessary data: *"It should be said that our company is relatively dominant, so upstream and downstream suppliers will provide relevant information according to the company's requirements"* (S2). Regarding verification, similar concerns are voiced compared to buying firms. There always remains a degree of uncertainty regarding the validity of suppliers' data (S2), and assessing the validity is very resource demanding (S4).

4.3. Current practices in supplier sustainability assessment and the role of digital technologies (RQ 3)

4.3.1. Scarce application of digital solutions in sustainability-related data collection and exchange between suppliers and buyers (RQ 3.1)

We wanted to find out which role digital technologies play both in the analysis of sustainability-related criteria by buying firms, as well as in the collection and sharing of respective data by suppliers. Table 5 provides an overview of buying firms' and suppliers' tools used for data collection, sharing and analysis, and shows where digital solutions are already applied or still lacking. In general, buying firms highlight differences between capturing traditional KPIs or sustainability-related indicators with regards to the utilization of digital tools: *"When we talk about pricing or cost, we already have quite good digital tools for that. For topics like carbon footprint, or if I want to know whether there are human rights violations, we can only rely on the data we get from suppliers"* (B6). More specifically, low usage of digital solution is especially described regarding the collection and transmission of data from suppliers to buying firms. To a large degree, the collection of sustainability-related data of suppliers relies on self-assessment questionnaires which are sent out manually or digitally (B2, B3, B5, B9, B10). One interviewee mentions the difficulties of this procedure for later assessments: *"so when it comes to quality data (…) they have automated, automatically generated data, when it comes to social and environmental performance, then it is always provided through the suppliers themselves. So we for instance do not have an integrated link to their payment system, to make sure that what they give us as feedback on their salaries is actually accurate. We might ask them for download, but then still there is human intervention before we actually get the information"* (B5). Similarly, another buying firm recalls that when suppliers are asked about the data sources for self-assessments of energy use in production, they often find that this is not based on digital solutions for machine generated data, but rather based on manual estimations (B1). However, particularly larger buying firms report that they have developed digital solutions for centralized storage of suppliers' self-assessments that allows for later analysis and comparison, which is viewed as an improvement over manually managed spreadsheets (B6, B10).

From the suppliers' perspectives, a lot of experiences are echoed with regards to the collection of sustainability-related data from second-tier suppliers as well as at their own companies. They report that second-tier suppliers largely send results of self-assessments via

Table 5
Current practices and digital technology use in supplier sustainability assessment.

	Buying firms	Suppliers
	Current state	
Data collection & sharing	• Focus on self-assessment questionnaires (B2, B3, B5, B9, B10) • Initiation of centralized, internal storage of self-assessments (B6, B10) • Lack of digital interfaces to access sources for social sustainability claims of suppliers (B5) • Lack of sensor-based calculation of environmental friendliness of production in first-tier suppliers (B1)	• Reliance on second-tier suppliers self-assessment questionnaires (S2, S4) • Inability of real-time assessments due to lacking digital interfaces to second-tier suppliers (S8) • Missing integration of first-tier suppliers' sustainability data management from existing information systems (S2, S7) • Lack of special collection systems for sustainability indicators (S3) • Automated monitoring of internal sustainability-related data (S6)
Data analysis	• Personal audits (B3, B10) • No analysis of suppliers' claims (B9) • Validation through service providers (unspecified) (B6) • BDA to predict risks of non-compliance (B5)	• Validation of second-tier suppliers' claims through service providers (unspecified) (S2)
	Future outlooks	
Data collection & sharing	• Shared database to assess environmental risks of product inputs (B8) • Platforms to share suppliers' sustainability performance (B10)	• Real-time monitoring of resource consumption in production (S3)
Data analysis	• Blockchain-based validation of product carbon footprints (B6)	

e-mail, with limited options of digitally accessing data sources (S2, S4). Similarly, some suppliers criticize a lack of data collection of sustainability-related criteria in second-tier suppliers and highlight the disadvantages of not having digital solutions in terms of data availability and timeliness: "*Some suppliers' production data is not available in real time and data transmission is lagging behind*" (S8). Moreover, suppliers are critical of the maturity of their own data collection processes with regards to sustainability-related criteria. Digital solutions have not been elaborated, as one interviewee states, "*there is no special collection system for internal environmental or social indicators*" (S3). Likewise, other suppliers mention that they greatly rely on manual records or digitalized spreadsheets, but that this data is not stored in central databases or connected to existing information systems (S2, S7). Only one supplier states that "*for internal data, automatic monitoring system records are mainly used*" (S6).

4.3.2. Mixed approaches in the use of digital technologies for data analysis

Although limited assistance of digital technologies in the collection of data on sustainability-related criteria is reported, companies differ in the degree to which digital solutions are applied in the analysis of respective data. Some buying firms state that they rely on in person audits to verify suppliers' sustainability claims (B3, B10). However, another firm expresses that this approach has proven to be highly ineffective: "*If you look at the situation today, despite all the efforts in digitalization, the majority of companies, they try to engage their suppliers, do that through third party audit companies, but what we found at least is that auditing, especially doing that in a manual way, is very ineffective to create transparency. Because suppliers can get very creative in passing the hurdle of an audit, without really making sustainable changes*" (B5). Another interviewee states that they skip an analysis altogether, citing limited resources: *"Who really has the time to measure these things?"* (B9). Against this backdrop, another buying firm highlights the reliance on third party services to provide sustainability analyses of suppliers: *"Concerning the evaluation of data, there are service providers who do these things (…) who check if suppliers are conforming to sustainability criteria"* (B6). Still, there are also cases in which buying firms utilize more sophisticated means of BDA to correlate suppliers' reports on different indicators (B1), or to project developments of supplier performance in a specific area to determine the risk of non-compliance with sustainability criteria, for instance (B5). As a consequence, they facilitate a more efficient risk management of suppliers: "*And so, from that we are already now able to predict quite well where the biggest risks will be in our supply base, to make sure if we are going to do an engagement, if we are going to make that investment, that we do that with our suppliers that are then at the highest risk, also have the highest need to get that support*" (B5).

Suppliers made very few comments if they analyze respective data coming from second-tier suppliers, or if they simply share it with buying firms upon request. Although the validity of sustainability-related data coming from second-tier suppliers is questioned, one supplier refers to the lack of internal resources for data verification and for the need to outsource data analysis to third party service providers (S2).

4.3.3. Future outlooks: Use of digital technologies in supplier sustainability assessment (RQ 3.2)

We asked interviewees to assess how the use of digital technologies for sustainability-related supplier selection will change in the future. Generally, we find that they believe that not only the use of digital technologies in supplier management will increase, but that this will also be beneficial for supplier sustainability assessment: *"I also believe that through higher data transparency (…) we will be much better at evaluating sustainability. Personally, I view digitalization as very positive, in sum"* (B6). One supplier expresses similar beliefs, especially regarding real-time monitoring of energy and material consumption (S3). However, assumed mechanisms and potential fields of application are only specified in a few cases. Multiple buying firms highlight the potential of blockchain-based solutions to improve transparency, especially of the environmental impacts of production (B2, B6, B8). One interviewee expresses that *"If I could wish for one thing, that would absolutely be blockchain for tracking and tracing of product carbon footprints"* (B6). Although less specific about the technological solution, one supplier also highlights the role of digital solutions for the collection and analysis of data that is necessary *"for the calculation of carbon emissions for the whole supply chain"* (S1).

As another envisioned field of application, buying firms underscore the relevance to increase industry-wide transparency through digital technologies. Thus, centralized databases for certain indicators as well as collaborative platforms are expected to be beneficial for supplier sustainability assessments. Based on blockchain as well, one buying firm envisions the establishment of a database that carries all relevant information with regards to the environmental effects of all product inputs (B8). Moreover, another buying firm wishes for a broader use of collaborative platforms to share data on sustainability assessments:

"working with sustainability has to go from individual companies working with sustainability to a more collaborative approach, where supplier can share data (…) so that many customers can make use of this data" (B10).

5. Discussion

5.1. Criteria evaluated in the selection of suppliers

Even though many buying firms reflected the increasing importance of considering social and environmental issues in supplier selection (Pagell and Wu, 2009), our results suggest different reasons as to why supplier sustainability assessment may not play an instrumental role in some companies' SSCM efforts. Firstly, the majority of interviewed suppliers (5 out of 8) stated that they were not asked by buying firms to report their performance on sustainability-related indicators. This is not necessarily a contradiction to buyers' statements because the interviewed suppliers were not asked about their relationship to the interviewed buyers. However, it indicates that endeavors of stakeholder networks in the electronics industry have not yet proliferated extensively. In fact, in a related study Wilhelm & Villena (Wilhelm and Villena, 2021) show that more than 40% of investigated suppliers in the electronics industry were not engaged in such networks. Secondly, buying firms' statements suggest differences in the relative importance of suppliers' performance in specific sustainability-related criteria. That is, a lack of reporting on sustainability-related criteria only leads to the exclusion of suppliers for some criteria, but not for all. Contrasting Lund-Thomsen & Lindgreen's (Lund-Thomsen and Lindgreen, 2014) findings, some interviewed buying firms appear to prioritize social sustainability aspects (e.g. adherence to labor standards) when analyzing suppliers' sustainability performance, a dimension that remains understudied in the scientific discourse (Fritz et al., 2017). This is also at odds with more recent studies highlighting prioritization of environmental criteria to foster supply chain sustainability in manufacturing sectors (Kusi-Sarpong et al., 2019). Still, this could be explained by an increasing awareness of the fact that social issues are especially prevalent in developing countries (Govindan et al., 2021).

We have also assessed the relevance of suppliers' performance regarding criteria related to digitalization and information exchange to investigate if buying firms actively try to overcome issues of data availability and validity in supply chains. We found that buying firms valued these criteria very differently. Whereas some buying firms stated the existence of compatible digital interfaces with suppliers as a prerequisite, others were less demanding, as long as other (higher valued) criteria are met. Surprisingly, these views did not seem to differ between large buying firms with sizeable and dispersed supplier bases and smaller buying firms with more clustered supplier bases. For both groups, we found contrasting views regarding the availability of digital solutions for information exchange with suppliers. To concur with previous findings, the establishment of IT links between buying firms and suppliers should receive more attention from firms, since these are perceived as prerequisites of information sharing in the approaching Industry 4.0 setting (Müller et al., 2020). Moreover, "willingness to exchange data" is the only criterion in which buyers' demands and suppliers' perception of importance substantially differ. This means that the average interviewed supplier perceives their own willingness to exchange data as less important than what buyers demand or expect. In conclusion, buyers appear to have heterogeneous data processing needs and capabilities (Busse et al., 2017) that suppliers may not always be aware of.

5.2. Factors influencing supplier sustainability assessment

We have investigated perceived boundary conditions of supplier sustainability assessment and clustered interviewee statements into four categories ("organizational", "buyer–supplier dyad", "supply chain / network" and "society / stakeholders").

Our results concur with previous findings (Giuffrida and Mangiaracina, 2020) in the sense that binding legal norms are an important driver of supplier sustainability assessment. On the one hand, awareness and acceptance of laws and regulations related to SSCM may appear self-evident, but in reality existing norms are often not enforced (Lund-Thomsen, 2008), leading to a lack of adherence. Although scarce, the specificity with which some buying firms describe potential changes in the landscape of regulation in certain areas implies awareness for the potential need to adapt current practices. Awareness of potential global changes to the legal framework could not be detected in suppliers, focusing rather on domestic laws and regulations. On the other hand, policy makers in many areas have yet to prove their willingness to implement more encompassing regulation (Clarke and Boersma, 2017), questioning the likelihood of establishing comparable global standards for a variety of sustainability-related indicators in the near future. Moreover, it appears more likely that legal frameworks tackle questions of what to address rather than prescribing tools for data collection and analysis, requiring companies to continuously evaluate the feasibility of different technological approaches to support this process.

With regards to the level of "supply chain / network", especially supplying firms expected rising requirements concerning data provision and analysis in the context of sustainability assessments. This was seen as likely to increase with increasing business partners due to multi-sourcing and diversification. From the perspective of buying firms, especially larger firms with already complex and non-transparent supplier networks expressed the need to prioritize certain suppliers, e.g. according to perceived risk of non-compliance (Grimm et al., 2016) for sustainability assessments. Hence, it can be concluded that data processing capabilities will need to increase if a relevant share of suppliers is ought to be assessed in terms of sustainability. Assuming the increasing complexity of supply chains does not only occur between buying firms and first-tier suppliers, firms will also need to dedicate more resource to increasing the visibility of indirect relationships with lower-tier suppliers to ensure the effectiveness of supply chain wide sustainability assessments (Fraser et al., 2020c).

Concerning the level of "buyer–supplier dyad", both buyers and suppliers emphasize issues resulting from suppliers' unfamiliarity with sustainability assessment criteria. Moreover, suppliers mention a lack of clarity in formulating data requirements from buyers. Previous studies have documented issues of sustainability compliance due to suppliers' unfamiliarity with requirements (Wilhelm et al., 2016). To clarify expectations and avoid misconceptions, companies should aim to specify not only the data required, but also the format and relevance of proof to overcome the stated obstacles of analyzing data. Thus, the issue of standardization relates to both the quality and quantity of information with regards to sustainability performance. For this purpose, the use of digital solutions appears particularly useful. Instead of investigating suppliers' approaches to self-assessments in hindsight, creating digital interfaces to match requirements with data provided prevents misinterpretation and allows real-time assessment and immediate feedback. Secondly, the responses of suppliers echo previous findings regarding the assumption that cascading of supplier sustainability assessment usually starts with the buying firm (Wilhelm and Villena, 2021). With the exception of one supplier, interviewed first-tier suppliers only collected information on sustainability-related indicators from second-tier suppliers if they were asked to do so by buying firms. Conversely, first-tier suppliers explicitly mentioned the lack of buying firms' demands as a reason not to perform sustainability assessments of second-tier suppliers. On the one hand, this implies a general willingness of first-tier suppliers to communicate sustainability obligations down the supply chain. On the other hand, this raises doubts about the efforts of buying firms to strategically adopt a supply chain perspective with regards to sustainability performance (Comas Martí

and Seifert, 2013). Moreover, it exposes the largely extrinsic motivation of suppliers to engage in supplier sustainability assessments in the form of pressure from other actors (Khattak and Pinto, 2018). This raises further doubt about the effectiveness of supplier sustainability assessment in contributing to SSCM if suppliers do not perceive or are unaware of potential benefits. Besides benefit sharing (Müller et al., 2020), willingness to share information can also be fostered by establishing a shared vision between supply chain partners (Jira and Toffel, 2013), further emphasizing the importance of collaborative strategic alignment.

5.3. Role of digital technologies in supplier sustainability assessments

With regards to data collection and exchange, both buyers and suppliers state that they largely rely on their respective suppliers' self-assessments concerning sustainability, equally criticizing a lack of digital interfaces to the data sources on which self-assessments rest for both social and environmental indicators. Moreover, suppliers critically assessed their own procedures, highlighting a lack of standardized data collection procedures and the absence of information systems for the integration of sustainability-related data. Low degrees of digitalization did not only influence data availability, but also timeliness, impeding real-time sharing of data. Thus, supplier sustainability assessment may be negatively affected by, in the best case scenario, isolated and heterogeneous data collection of supply chain actors. As Zhang et al. (2017) underline, most data mining only focuses on a single stage of the product's life cycle. Consequently, isolated life cycle data often times cannot be integrated into traditional IT architectures (Gandomi and Haider, 2015), highlighting the need for industry-spanning standardized communication protocols for data interfaces to enable exchange between supply chain partners (Kache and Seuring, 2017; Kiel et al., 2017). Given the currently low adoption rate of digital technologies in supplier sustainability assessment, focal companies should be concerned with fostering this harmonization of data exchange to extract meaningful information which is based on data that arises at different nodes in the supply chain, such as product life cycle data. This would also reduce the burden on the limited resources of suppliers who could instead aim to invest in underlying digital infrastructure to facilitate data collection in the first place, for instance by retrofitting and interconnecting machines and devices. In general, especially in long-lasting relationships between supply chain actors, a more explicit discussion of and roadmap for responsibilities regarding data collection and exchange could make it easier to allocate resources to e.g. tools to improve quality of internally captured data at each node instead of requiring external services for data analysis and validity assessment. From the buying firm's perspective, this would also facilitate a more efficient supplier management given the need for continuous evaluation of suppliers' performance (Ghadimi et al., 2016).

In the context of supplier sustainability assessment, it is worth noting that numerous interviewees – both buyers and suppliers – stated that they did not engage in further analysis of suppliers' sustainability claims, which was often explained by a variety of constraining factors, such as time or data processing capabilities. Hence, only a few companies employed BDA or similar means to assess and predict suppliers' risk of non-compliance. Concurring with Dubey et al. (2019), despite high expectations, the majority of companies have yet to capture the benefits of BDA in enabling SSCM. Similar to the perception of an interviewed buyer, Lund-Thomsen (2008) questions the usefulness of manual audits. Generally, interviewees conveyed the impression of relying on third party service providers for data analysis regarding supplier sustainability assessment. Thus, the current neglect of data analysis seems to be an issue of available capabilities and technical feasibility, rather than lack of willingness. However, it could also imply that SSCM goals are rarely considered for technology implementation (Giuffrida and Mangiaracina, 2020). In the long run, lacking the means to verify sustainability claims impedes potential collaboration with suppliers to improve SSCM practices, increasing the likelihood of revealing misconduct, especially in complex supply chains.

To cope with issues of transparency and improve supplier sustainability assessment, some interviewees expressed how their companies could benefit from the use of digital technologies in the future. However, these were largely restricted to buyers' statements, raising further doubt on the strategic consideration of digital technologies for supplier sustainability assessment in many companies. Regarding data storage and collection, the use of shared platforms is seen as fruitful. Ebinger and Omondi (2020) highlighted that industry-wide action is already taking place, allowing companies to share their performance with other users. Moreover, there are also indications that issues of data validity and verification are of concern and could be improved through digital technologies. Multiple buying firms envision blockchain-based solutions to facilitate the assessment of environmental impacts of production, especially of carbon emissions. Similar to BDA, the implementation of blockchain in industry is still scarce (Pournader et al., 2020). Also, the question of data sources remains, emphasizing the benefits of integrated approaches based on RFID or similar technologies (Saberi et al., 2019). Hence, such solutions might be more suitable for specific indicators. In this regard, we find a certain disconnect from the stated (high) importance of adherence to social standards and interviewees' outlooks regarding potential future use cases of digital solutions for supplier sustainability assessment which largely address environmental issues. As Wilhelm et al. (2016) hold, it is easier to trace compliance with indicators of environmental sustainability. Conversely, it is difficult to rule out human intervention for the assessment of a variety of social sustainability indicators. Ideally, when considering the implementation of new technological solutions, companies shall not only reflect upon the importance of specific sustainability indicators, but also upon the implications for standardized data exchange along the supply chain. As Schöggl et al. (2016) find, fully structured exchange of sustainability data only takes place for a narrow set of indicators, none of which relate to social issues.

6. Conclusion

Recent research suggests that the utilization of digital technologies for supplier sustainability assessments offers untapped potential which may benefit a variety of processes related to the exchange, collection and analysis of sustainability-related data of different companies in a supply chain (Garcia-Torres et al., 2019; Ebinger and Omondi, 2020). This study contributes empirical evidence to the scholarly discussion about current practices of supplier sustainability assessment and related use of digital technologies in the electronics industry, employing a qualitative, interview-based approach. In drawing our conclusions, we feed back our findings into the conceptualization of our research approach (Fig. 1) to depict a framework that emphasizes the interconnectedness of our research questions and outlines future research opportunities (Table 6). Thus, we reflect upon the three issues of supplier sustainability assessment ("What?", "Why?", "How?") described in the introduction.

Firstly, with regard to applied selection criteria, our results imply that supplier sustainability assessments currently do not play a central role for supplier relationship management when compared to more traditional performance indicators. Likewise, we found differences in the relevance attributed to the manifold sustainability-related supplier selection criteria which suggest stronger consequences in case of non-compliance for some of the social sustainability indicators, although more research is needed for confirmation. Moreover, although companies face issues of data availability and validity regarding suppliers' performance, we find no clear trend that all buying firms aim to ensure availability and compatibility of digital interfaces by selecting suppli-

Table 6
Key findings and future research opportunities.

Constructs	Key findings	Future research opportunities
What? (Assessment criteria)	• Differences in the relative importance of sustainability criteria • No strategic consideration of compatible digital interfaces to suppliers	• Context-dependency of the prioritization of different sustainability criteria in supplier selection
Why? (Boundary conditions)	• Awareness of sustainability data requirements (quantity, quality) influenced by lack of standardization. Potential alleviation through digital real-time assessments • Importance of fostering willingness to share information with SC partners	• Role of strategic alignment along the SC in terms of sustainability goals to foster data collection and exchange
How? (Tools, technologies)	• Lack of standardized data collection procedures at suppliers • Missing digital interfaces complicate verification of sustainability claims • Individual verification of sustainability claims at each SC node too resource demanding, especially at lower tiers	• Investigation of digital solutions to overcome issues of limited structured data exchange which are present in the assessment of many social sustainability criteria

ers accordingly. This suggests a lack of strategical consideration of technology implementation to foster SSCM.

Secondly, boundary conditions frame how companies perform supplier sustainability assessments. Expecting increasing complexity of supply chains and an increase of business relationships, companies are advised to implement scalable digital solutions to perform sustainability assessments on a relevant share of suppliers. From the suppliers' perspective, potential for misunderstanding of information requests is caused by a lack of standardization which relates to both the definition of indicators and the properties of data (quality and quantity). In this regard, digital technologies provide solutions for real-time feedback regarding the match between data requirements and data provided, reducing the need of manual ex-post analysis of data suitability. However, a necessary first step should be to consider how to ensure greater willingness to share sustainability-related information, which also requires communication of shared benefits in the first place (Müller et al., 2020). This gains further importance due to the fact that first-tier suppliers report similar obstacles when collecting information from lower-tier supply chain partners. Hence, one avenue for future research lies in the investigation of means to not only identify lower-tier supply chain partners, but on how to facilitate strategic alignment in terms of sustainability goals between partners. Creating shared visions, benefits may become more tangible for self-declared non-beneficiaries of increased scrutiny, e.g. through intensified relationships or positive outside communication.

With regards to the third question relating to tools and technologies, we find that buying firms currently rely on suppliers' self-assessments of sustainability performance for a vast majority of indicators. This is also true for the information exchange between first-tier and second-tier suppliers. Moreover, buying firms greatly differ in the way they proceed with respective data. Whereas some buyers do not try to verify or analyze such data at all, others employ BDA to assess suppliers' sustainability performance and risk of non-compliance. However, such use cases appear to still be rare (Liu et al., 2020). Companies have started to recognize the potential benefits provided by digital solutions. Digital platforms provide easy to access databases to share sustainability assessments beyond the supply chain. Still, it should be viewed with caution that suppliers have limited resources for the analysis of lower-tier suppliers' sustainability claims, and that buying firms appear to focus on digital solutions for environmental sustainability. In line with the fact that some sustainability issues require information from all supply chain actors, the implementation of suitable digital solutions requires concerted efforts. Citing the stated low ability of first-tier suppliers to verify lower-tier sustainability claims as well as their own limited resources for structured and automated data collection, prioritization of the different steps towards digital information sharing between supply chain partners should be considered. In a first step, improvements of the means for digital data collection should be aimed for at individual firms. On an overarching level, industry-wide efforts should focus on developing easy-to-use tools for recording sustainability parameters as well as standardized and non-proprietary data models, which allow for data exchange along the entire supply chain. This becomes increasingly important assuming an increase in the amount of supply chain partners and the complexity of relationships between firms. Furthermore, future research opportunities relate to the previous two questions, touching upon the sustainability indicators for which information is requested, standardization of requests and digital assistance. The use cases of Industry 4.0 technologies currently described largely relate to environmental issues, whereas their suitability to provide transparency of social issues in supply chains is not well researched. Additionally, an investigation of current technology use for sustainability data collection and exchange at lower tiers could help to map specific obstacles to overcome regarding different production stages, for instance.

6.1. Implications for theory and practice

Our study provides multiple insights for the scientific discussion. Firstly, procedures of and tools used for supplier sustainability assessment are still not very well researched (Fraser et al., 2020b), providing a useful case to exemplify the potential sustainability-related benefits of Industry 4.0, for which empirical investigations have also been called for (Ghadimi et al., 2019). Secondly, we relate the rising relevance of social sustainability criteria for supplier assessments to issues of structured data exchange for such indicators (Schöggl et al., 2016), calling for further investigation to reveal technological solutions or assistance. Thirdly, we showcase the issue of not having a comprehensive scientific view on sustainability measurement (Mura et al., 2018). Scholars increasingly seek to describe antecedents and consequences of information sharing on sustainability performance in GSCs (Dahlmann and Roehrich, 2019). Considering varying boundary conditions, insights should be fed back into the establishment of a framework addressing the possibility of Industry 4.0 to support SSCM (Chalmeta and Santos-deLeón, 2020).

From a managerial perspective, we highlight the need for strategic considerations of technology implementation for supplier sustainability assessment. Acknowledging limited resources especially of SMEs, we emphasize the importance to streamline and standardize processes of sustainability data collection and exchange, clearly defining responsibilities of data availability and validity while facilitating infrastructure for automated exchange among and beyond supply chain nodes. Furthermore, companies should continue to collaboratively leverage their bargaining power to enhance standards of sustainability assessments (Wilhelm and Villena, 2021), while staying open to considering different views on sustainability issues (Busse et al., 2016).

With regards to the implications for policy makers, our study concurs with previous studies describing both the need for further legal norms (Ghadge et al., 2019) and for the enforcement of established policies (Badri Ahmadi et al., 2017). Given the nature of GSCs, legally binding norms should span all jurisdictions of all actors involved in the supply chain and be aligned with the ongoing voluntary efforts in the industry, while retaining adaptability to the latest scientific insights and the broader societal concerns for sustainable supply chains. Policy issues are also cross-cutting, requiring guidance on the type of information required, but also on data security (Veile et al., 20192020) to foster companies' willingness to exchange information, for instance. Moreover, financial constraints of technology implementation (Luthra and Mangla, 2018) could be overcome by incentives to employ the means to ensure data availability and validity.

6.2. Limitations

Our study is subject to some limitations. Firstly, our sample size does not allow generalizability of insights. Although we aimed to reach a broad range of supply chain professionals, reachability especially of supplying firms without direct contact to their buying firms proved difficult. However, given the scarcity of empirical insights at the interface of SSCM and digitalization, we consider our exploratory approach as an enrichment for the discussion. Secondly, social desirability of interviewees' replies cannot be ruled out entirely. This should also be taken into consideration in the light of various pressing SSCM issues in different regions of the world and corresponding policy measures in influencing firms' approaches and views. We aimed to overcome a one-dimensional, potentially biased point of view by matching suppliers' questions with buyers' questions. In this regard, we point out again that our interviewed suppliers do not necessarily have business relations to the interviewed buyers, which we did not assess due to reasons of discretion and business secrets, but also due to our perceived irrelevance for exploration purposes. Thus, we cannot derive conclusions for the relationship of a buying firm – supplier dyad in two specific regions or countries. Lastly, we did not investigate whether the COVID-19 pandemic and its impacts on supply chains influenced the procedures of supplier sustainability assessment and its relative importance compared to other criteria.

6.3. Future outlooks

There remain ample opportunities to bridge the gap between sustainability and digitalization in the context of GSCs. Scholars should be encouraged to consider practitioners' circumstances and needs to gain a better understanding of how digital solutions for SSCM can be implemented effectively in heterogeneous settings, sharing insights on situational obstacles and benefits. Ultimately, handling of sustainability-related supply chain data should not be seen as a separate procurement and SCM issue, but instead be considered an integral part of supplier management.

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CRediT authorship contribution statement

Marcel Matthess: Conceptualization, Methodology, Investigation, Writing – original draft. **Stefanie Kunkel:** Conceptualization, Investigation, Writing – review & editing. **Bing Xue:** Resources. **Grischa Beier:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix A Interview guideline (buying firms)

1. Please describe your position in the company and your responsibilities and your disciplinary background.
2. What do your supply chain (SC) processes look like regarding procurement (and reverse logistics) and cooperation with suppliers?

- How do you proceed in terms of:
  - Identification of suppliers
  - Choice of suppliers
  - Other collaborative processes with supplying companies
- Can you tell us what current challenges you are facing with regards to these processes?

3. How many suppliers does your company have and how are they geographically distributed?
4. Estimate/Please rate: How important are the following aspects to you regarding the suppliers' performance on a scale from 1 to 10, 1 being not important at all, 10 being very important

- Transparency
- Price
- Quality
- Compliance with scheduled delivery dates
- Recommendation from other partners
- Gigital equipment and know-how,
- Willingness to exchange data on the part of the suppliers for their integration into the supply chain?

5. What data do you collect in the course of procurement?

- What data do you collect on environment and social indicators?
- Is there also a mutual exchange of data between your suppliers and your company?

6. Which tools do you use in detail for the collection and assessment of data (Excel, e-mail, ERP, EDI, others…)?

- Do you use any specific tools for the storage and analysis of data on social and environmental indicators?

7. What are obstacles in the collection and assessment of data?

- Are there any specific obstacles when it comes to the collection and assessment of data on social and environmental indicators?

8. Do you already use big data analytics (and artificial intelligence) to generate information about your suppliers? If so, for what purposes?

- Just to clarify: We view big data analytics as a technical means to gather and analyze large amounts of unstructured and heterogeneous data.

9. If not: Do you already use big data analytics in other SC processes?

10. Can you imagine using (other) digital technologies in SC management in the future?

- For instance, can you think of instances in which algorithms could optimize decision making processes? Are there cases in which tools that are able to give meaning to existing data would assist your work?

11. Which economic, ecological and social effects of the use of digital technologies do you observe or do you expect to observe in the future in your company/at your suppliers?

12. Estimate: How will the use of digital technologies influence the below aspects? Please rate on a scale from −5 to 5 (−5 probably very negatively, 0 probably neutral, 5 probably very positive).

- Exchange of data on the environment and social issues (transparency)
- Transfer of knowledge about the use of energy- and resource-efficient manufacturing technologies and processes
- "Green" innovative ability
- Compliance with legal and voluntary reporting standards on environmental and social aspects
- Involvement of (new) suppliers in the value chain
- Employment and wages in supplier companies

13. Imagine you could reinvent the existing SC processes in the area of sourcing (and possibly reverse logistics): Which processes would have to change and which tools and technologies would be needed to make processes more ecologically and socially beneficial?

Appendix B Questionnaire (suppliers)

Welcome, thank you for your willingness to participate, reminder of the goals of the study, **permission to record?**

1. 欢迎, 感谢您的参与, 提醒您此次研究目的, 是否允许会议记录?

2. Please describe your position in the company, your responsibilities, your age and your disciplinary background, particularities of supply chain management in the electronics branch

2. 请描述您在公司的职位, 您的职责, 您的年龄以及学术背景, 电子行业供应链管理的特性

3. How many branded firms does your company supply and how are they geographically distributed?

3. 贵公司共供应多少品牌公司?他们的地理分布是怎样的?

4. How many suppliers does your company have and how are they geographically distributed?

4. 贵公司有多少的供应商?他们的地理分布是怎样的?

5. What do your supply chain (SC) processes look like regarding cooperation with both branded firms/OEMs and your suppliers?

5. 对于品牌公司/原始设备制造商与贵公司供应商之间的合作, 您的供应链流程是怎样的?

6. Please rate each on a scale from 1 to 10: How much do the branded firms that you supply value the following aspects in you:

6. 请按1至10比例评分:您供应的品牌公司在以下方面对您是怎样评估的?

- Transparency 透明度
- Data availability 数据可用性
- Price 价格
- Quality 质量
- Stick to delivery dates 确保交货日期
- Recommendation from another firm 其他公司推荐
- Digital equipment and know-how 数字化设备及专业技能
- Willingness to exchange data 交换数据的意愿

7. What data do branded firms demand from you, including about environment and social indicators?

7. 品牌公司需要您提供哪些数据?包括环境及社会指标?

8. What data do you demand from your suppliers?

8. 您需要从供应商那里得到哪些数据?

- Do you also collect data on environmental and social indicators?
  您也需要收集环境及社会指标数据吗?

9. Which tools do you use in detail for the collection, transmission, and assessment of data (pencil & paper, excel, e-mail, ERP, EDI, others…)?

9. 您在收集, 传输及评估数据时使用了哪些工具?(铅笔和纸张, excel, 电子邮件, ERP, EDI, 或其他…)

- If you collect data on environmental and social indicators: Which tools do you use for that?
  如您收集了环境及社会指标数据:您使用到了哪些工具?

10. What are obstacles in the collection and assessment of data?

10. 在收集及评估数据方面有哪些障碍?

- What are specific obstacles with data on environmental and social indicators?
  在收集环境及社会指标数据时有哪些具体障碍?

11. Do you already use big data analytics and/or artificial intelligence in the cooperation with branded firms? If so, for what purposes? Descriptive or prescriptive? Also for ecological or social purposes?

11. 在与品牌公司合作时您是否已经运用到了大数据分析和/或人工智能?如果是, 您的目的是?描述性还是规定性?为了生态还是社会目的?

12. If not: Do you already use big data analytics in other SC processes?

12. 如果没有:您是否已经在其他供应链流程中使用到大数据分析?

13. If not: Can you imagine using specific digital technologies in SC management in the future?

13. 如果没有:您能想象在未来的供应链管理中会使用到的特定的数字技术吗?

- E. g. Do you use other tools to assess large amounts of unstructured data?
  例如:您使用过其他工具来评估大量的非结构化数据吗?
- Do you use algorithms to optimise decision processes?
  您使用过算法来优化决策过程吗?

14. Which ecological and social effects of the use of digital technologies do you observe or do you expect to observe in the future in your company/at the branded firms that you supply, e. g. with respect to energy use, resource use or wages in your company?

14. 您在贵公司/供应的品牌公司中观察或未来期望观察到哪些使用数字技术的的生态和社会影响?例如:能源的运用, 资源运用或公司工资方面?

15. Estimate: How will the use of digital technologies influence the below aspects? Please rate on a scale from −5 to 5 (−5 probably very negatively, 0 probably neutral, 5 probably very positively).

15. 请预估:数字技术的使用会怎样对以下几个方面产生影响?请按-5至5分段评分(-5 可能非常消极, 0 可能中立, 5 可能非常积极)。

- Exchange of data on the environment and social issues 环境和社会问题的数据交换
- Transfer of knowledge about the use of energy- and resource-efficient manufacturing technologies and processes 关于能源及资源高效制造技术和过程的知识转换
  - o In your company 对您公司
  - o At your suppliers 对您的供应商

- "Green" innovative ability "绿色"创新能力
  - o In your company 对您公司
  - o At your suppliers 对您的供应商
- Compliance with legal and voluntary reporting standards on environmental and social aspects
  遵守环境和社会方面法律及自愿报告标准
  - o In your company 对您公司
  - o At your suppliers 对您的供应商
- Involvement and captured gains of your own company in the supply chain
  您自己公司在供应链中的参与及收获
- Involvement of (new) suppliers in the value chain(新)供应商在价值链中的参与度
- Employment and wages in your own company 贵公司的工作及薪资
- Employment and wages at your supplier's 您的供应商的工作及薪资

16. Imagine you could reinvent the existing SC processes in the area of sourcing: Which processes would have to change and which tools and technologies would be needed to make processes more ecologically and socially beneficial?

16. 设想一下您能在采购中重新设计现有的供应链过程:哪个过程是必须改变的?哪些工具及技术会使整个流程更具生态及社会效益?

17. Optional: What are your current challenges in supply chain management?

17. 可选:您目前在供应链管理方面面临的挑战是什么?

18. Are there any other aspects that we haven't mentioned yet but which you would like to add because you think they are important?

18. 有没有其他方面我们没有提及，但您认为较重要并愿意补充?

19. Do you have contacts who might be willing to talk to us and share their expertise?

19. 您有愿意与我们交流并分享他们专业知识的联系人吗?

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