Journal of Cleaner Production 377 (2022) 134475

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Leveraging supply chain networks for sustainability beyond corporate boundaries: Explorative structural network analysis

Sini Laari [a,*], Philipp Wetzel [b], Juuso Töyli [a,c], Tomi Solakivi [a]

[a] *Operations and Supply Chain Management, University of Turku, Finland*
[b] *Institute of Supply Chain Management (ISCM-HSG), University of St. Gallen, Switzerland*
[c] *Department of Communications and Networking, Aalto University, Espoo, Finland*

A R T I C L E I N F O

Handling Editor: Jian Zuo

Keywords:
Sustainable supply chain management
Network analysis
Sustainable performance
Automotive industry
Supply chain network
Structural analysis

A B S T R A C T

The ability of companies to achieve systemic sustainability goals is influenced by the structure of the larger supply chain network in which they reside. However, managing sustainability throughout multi-tiered global supply chain networks and complying with new supply chain law initiatives has proven to be a great challenge for many firms. This article investigates node- (firm) and network-level network structural characteristics and their implications for sustainability. The empirical study first explores structural patterns in a network of 5458 companies and then focuses on a sub-set of 604 companies associated with the automotive industry. The following four sustainability archetypes were identified: impassive networks, environmentally focused networks, socially focused networks, and orchestrated networks. The article further specifies strategy options for lead firms, suppliers, and regulators in enhancing sustainability in each archetype. The most sustainable firms are typically the most central, not necessarily the ones closest to the customers. Regulators should target central firms for a ripple effect.

1. Introduction

The current trend of disaggregating global supply chains increases the need to expand sustainability efforts beyond firm boundaries (Koberg and Longoni, 2019). While increasingly more companies are disclosing sustainability information, corporate reports may be overly optimistic about companies' actual practices, especially when it comes to ensuring the sustainability of the entire supply chain, where unsustainable practices can be hidden (Govindan et al., 2021). For example, clothing and textile companies are frequently criticized for maintaining sweatshop-like labor conditions or for creating a throwaway fashion culture (Pedersen et al., 2018). In May 2021, a Dutch court issued a historical ruling that oil and gas giant Royal Dutch Shell was partially responsible for climate change and ordered the company to cut its global carbon emissions by 45% (Wall Street Journal, 2021). The court found Shell's sustainability policy to be "insufficiently concrete" (Guardian, 2021). While the market for environmental, social and governance (ESG) data has steadily grown (Gyönyörová et al., 2021), ESG measures are of little use if they do not account for activities throughout the firm's supply network.

The necessary extension of the concept of sustainability beyond the boundaries of the company is shown by the discussions on supply chain law initiatives taking place in many countries and regions, which will hold companies liable for environmental and human rights violations. For example, French and Norwegian corporate due diligence laws are already in force, and there are legislative proposals put forward in the Netherlands and Belgium (European Coalition for Corporate Justice, 2022). While the German Government has come to an agreement concerning a law on supply chain due diligence that is expected to come into force in 2023, the Swiss voters rejected in a 2020 referendum the proposed due diligence legislation (Deutscher Bundestag, 2021; Schuerch and Biggoer, 2021). The European Parliament, in turn, has drafted a proposal for EU directive on mandatory human rights, environmental, and good governance due diligence to oblige firms to prevent adverse impacts in their supply chains (European Commission Proposal 23.2.2022). The proposal will be next presented to the European Parliament and Council for approval and thereafter the EU member states will transpose the directive into mandatory national law. These initiatives will require firms to identify and monitor risky suppliers and take appropriate actions to prevent and remedy negative impacts, with legal consequences for violations. The EU requirements will likely not be limited to the first tier, but the due diligence should encompass any

* Corresponding author.
E-mail addresses: sini.laari@utu.fi (S. Laari), philipp.wetzel@unisg.ch (P. Wetzel), juuso.toyli@utu.fi (J. Töyli), tomi.solakivi@utu.fi (T. Solakivi).

https://doi.org/10.1016/j.jclepro.2022.134475
Received 22 April 2022; Received in revised form 14 September 2022; Accepted 29 September 2022
Available online 6 October 2022

suppliers or sub-contractors that may pose major risks. For these reasons, introduction of the directive may be a game changer for human rights and climate change not only within the EU but also globally. However, ensuring that sustainability reaches the second-tier suppliers and beyond is a challenge for companies owing to the complexity and low visibility of globalized supply chain networks (SCNs) (Wilhelm et al., 2016b).

Researchers have increasingly investigated how supply chain members from multiple tiers are linked with each other to address sustainability issues. Although supply chain management (SCM) has long recognized the importance of wider supply networks and acknowledged that firms' network building can contribute to sustainable behavior, empirical investigations have typically taken dyads or triads as a unit of analysis (Choi and Kim, 2008; Meqdadi et al., 2019). Thus, understanding the role of the structural properties of SCNs in sustainability remains limited and lacks empirical grounding (Alinaghian et al., 2020). Structure thereby refers to the characteristics of an SCN, such as how many suppliers or customers belong to the firm's network or how dense the relationships among the members are (Choi and Kim, 2008). While the network structures are complex and often invisible, they heavily influence how companies achieve their sustainability goals (Alinaghian et al., 2020). When a buying firm forms a relationship with a supplier, it is indirectly linked with the supplier's network – whether or not it wants it to be (Hartmann and Moeller, 2014). Importantly, both the buyer and the supplier are embedded in a larger supply chain network (Yang et al., 2022).

Increasing supply chain due diligence requirements from regulators and consumers push firms to consider their SCNs and business models (Hofmann et al., 2018). However, sustainability, along with other outcomes, is affected not only by the actor's isolated relations with other actors but also by the structure of the larger SCN where the actor resides (Choi and Kim, 2008). The actions of firms, therefore, need to be viewed from both the firm and network levels.

In this article, we bring together the literature on SCNs examining the implications of network structure for knowledge and information flows and the literature on sustainable supply chain management. The purpose of this study is to identify network structural characteristics and their implications for sustainability and performance.

Applying the tools of network analysis, we examine the role of network structural properties for unique firms and for clusters of firms in facilitating or limiting sustainable performance. We rely on inductive, data-grounded reasoning partly because the use of multi-tier and network perspectives is still limited and requires exploratory theory building (Sauer and Seuring, 2017). Furthermore, this data-grounded exploration enables us to answer the call for network-level work to complement previous, mostly conceptual, anecdotal or single-case studies (Alinaghian et al., 2020; Provan et al., 2007). The empirical data comprise a real-world network consisting of 5458 publicly listed companies, combined with ESG data collected by financial and ESG data provider Refinitiv. Focusing on a smaller sub-set of firms connected to the automotive industry, we detect top firms and communities of firms and examine network structures that can be critical determinants of their success, or their failure. The automotive industry is well suited for a more in-depth analysis and allows for implications to other industries as well. This is because, on one hand, it plays a significant role in the world economy and is characterized by highly globalized SCNs. A major share of production is conducted by suppliers, and therefore supply chain design is a key competitive capability. Although carmakers are increasingly shifting from short-term contractual relationships to more long-term collaborative governance recent research suggests that their sustainability efforts have mostly focused on their own company instead of the entire supply chain (Paolucci et al., 2021; Siems et al., 2021). On the other hand, while stakeholder pressures have led many automotive businesses to adopt sustainable supply chain management practices, there is still room for improvement (Mathivathanan et al., 2018). For example, Volkswagen lost almost one-third of its market value following the diesel emissions scandal in 2015, which also cast a shadow of doubt over the entire German manufacturing industry (Rhodes, 2016). At the same time, the automotive industry is one of the most covered industrial contexts in operations and SCM research (Behara et al., 2014). Consequently, focusing on the automotive industry allows us to fill a specific research gap in the literature. We add to the sustainable supply chain management literature by combining the following two different but complementary perspectives: the view from the individual firm and that from the network level. The firm-level perspective describes how the involvement of a firm in a network affects its sustainability actions and outcomes. The network-level focus, in turn, explains how the properties and characteristics of the network, such as centralization or density, affect the overall sustainability of the network (Provan et al., 2007), examining all network actors or as many as possible (Wiedmer and Griffis, 2021). This research also contributes to the literature on cleaner production as the relationships between companies and their suppliers and customers play important roles in the implementation and diffusion of sustainable production models, including practices related to purchasing, production and distribution (Almeida et al., 2013). Sustainable supply chain management allows manufacturing firms to have cleaner production through collaboration with supply chain partners (Trujillo-Gallego et al., 2021). As firms have increasingly outsourced parts of their production, ensuring the supply of sustainable products requires commitments from the whole supply chain. Integrated SCNs can therefore help network members to reduce their individual and joint environmental footprint (Almeida et al., 2013). Yet, previous research on the diffusion of cleaner production along supply chains has largely focused on the technical aspects (van Hoof, 2014). It is necessary to understand how the adoption of cleaner production can be encouraged through SCNs (Vieira and Amaral, 2016). The results of this study highlight the importance of network structures in disseminating cleaner production throughout the SCN.

Finally, the study provides recommendations for companies and policy-makers. Understanding patterns of how firms leverage the connections that develop because of their embeddedness in a network can aid reaching higher levels of sustainability in SCNs (Gualandris et al., 2021; Saunders et al., 2019). Despite an increasing degree of sustainability disclosure, some companies do not "walk the talk" (Meehan and Pinnington, 2021). Regulatory agencies can take action against greenwashing and influence the behavior of firms by enforcing laws and regulation (Gualandris et al., 2021). The results also feed into the discussion on supply chain laws and the role of the government in the diffusion of sustainable practices.

2. Theoretical framing

2.1. Supply chain network structures

The SCN concept emerged as a response to complex supply structures and the interdependent, interactive, and continuously evolving relationships between supply chain members (Braziotis et al., 2013). The terms "supply network" and "supply chain network" are often used interchangeably, but in line with Wiedmer and Griffis (2021), we use the term "supply chain network" to extend the focus from the upstream supply network to include suppliers, customers, and their partners. Network scholars argue that a network perspective provides a rich view by considering the various interactions taking place in the SCN (Bellamy et al., 2014; Borgatti and Li, 2009; Braziotis et al., 2013). To address the complexity of contemporary supply chains, researchers have increasingly applied social network analysis (SNA) tools to analyze the structural characteristics of a network (Wichmann and Kaufmann, 2016). SNA builds on network and graph theories and offers a way of mapping relationships between actors, visualizing the network structures arising from these relationships and analyzing them formally in mathematical terms (Han et al., 2020).

An implicit but central construct in studying network structures is embeddedness. Network levels are embedded in one another—individual actors belong to dyads, dyads to triads, etc.—and all of them are embedded in a larger network structure (Choi and Kim, 2008). Thus, within larger networks are embedded groups that interact with each other to such an extent that they could be considered separate entities (Alinaghian et al., 2020). The seminal paper by Granovetter (1985) distinguished embeddedness into two basic dimensions of structural and relational. Here we consider structural embeddedness, which refers to the configuration of an actor's network of relationships. Structural embeddedness, therefore, describes how a firm directly and indirectly environs itself with other companies (Choi and Kim, 2008). These structural characteristics have been examined from both the node and network levels (Alinaghian et al., 2020). The node-level perspective describes structural embeddedness in a network from a single firm's point of view and utilizes measures such as betweenness and closeness centrality, whereas the network-level perspective takes a "bird's eye view" on the overall network and measures concepts such as centralization and density (Kim et al., 2011).

The emergence of SCNs has been viewed from two distinct perspectives. According to the first, building relationships with suppliers and customers contributes to an emerging and complex network structure, while the second suggests that supply chain network structures emerge spontaneously and form random structures because many firms act independently and simultaneously (Wiedmer and Griffis, 2021). Networks tend to be clustered, meaning that firms interact more frequently or intensely with firms with which they are similar or complementary (Schilling and Phelps, 2007). Choi and Hong (2002) note that most SCNs have emerged organically rather than having been purposefully designed by a single entity. For example, buying firms can empower their first-tier suppliers to manage the rest of their suppliers, thus letting supply chain networks emerge (Wilhelm et al., 2016b). Hence, a single organization may try to manage a part of its SCN, but it has to accept the fact that distant parts of network are outside its influence (Johnsen et al., 2019). Pathak et al. (2014) built on four interrelated elements common to SCNs (firm level tasks, ties between firms, network level objectives and governance) to propose SCN archetypes. A hierarchical network with tiers of upstream suppliers represents a typical supply chain where the structure of the network strongly influences how firms interact.

The formation and management of SCN relations can therefore significantly affect a firm's behavior and strategies and implementation of practices and performance (Vandchali et al., 2021). Moreover, the connections and interconnections among the network members can promote or limit the diffusion of knowledge and practices (Marques, 2019). A central firm can exploit its position to maximize its own profits or orchestrate resources for the benefit of the whole SCN (Vurro et al., 2009; Gong et al., 2018). As centrality increases, firms are able to exert their power over their network to gain favorable exchange terms and to direct the more dependent party to act in a certain way (Vurro et al., 2009). Dependency is one of the factors a firm must consider when designing, developing, and restructuring its SCNs (Awaysheh and Klassen, 2010; Vandchali et al., 2021). Existing research has particularly considered buyer power, but recent research has also highlighted the central role of the first-tier supplier as a "super middleman" between buying companies and lower-tier suppliers (Mena et al., 2013). To disclose information to customers and other stakeholders, firms need to map out their SCNs and gather information on the provenance of their products, the results of product testing, and compliance with environmental and social standards, for example (Hofmann et al., 2018; Sodhi and Tang, 2019). However, as the distance increases, firms face a challenge with information gathering, assessment, and implementation (Awaysheh and Klassen, 2010). Distance can refer to geographical distance, cultural distance (differences between the cultures of the societies where the firms are located), or organizational distance (number of tiers between various actors) (Awaysheh and Klassen, 2010; Vandchali et al., 2021). It has also been suggested that the distance to end-consumer markets may shape practices and incentives (Bellamy et al., 2020; Gualandris et al., 2021). There is paucity of research exploring how these structural properties influence the ways firms achieve their sustainability goals (Alinaghian et al., 2020).

2.2. Supply chain network structures and sustainability

The structure of the relationships between network members and their position in the network shapes the structuring and interpretations of sustainable supply chain management (Vurro et al., 2009). Many significant resources lie outside the firm's borders—the firm is at the same time limited and empowered by the network of its external relationships (Ekanayake et al., 2017). A growing number of studies have highlighted the importance of the broader SCN in achieving sustainability (Krause et al., 2009). Alinaghian et al. (2020) identify two main streams; the first focuses on investigating the influence of network structural characteristics on sustainable behavior and performance, while the second focuses on examining the management of multi-tier supply chains from a sustainability perspective. Regarding the first category, for example, Vurro et al. (2009) combined the focal firm's centrality and network density for a sustainable supply chain management governance model. Saunders et al. (2019) examined how network brokers, such as local non-governmental organizations (NGOs), affect the development, adoption, and diffusion of sustainability initiatives. Cole and Aitken (2020) studied how supply chain intermediaries supported the establishment of a sustainable supply chain through information transfer, knowledge development, risk management, and capability support. Bellamy et al. (2020) discovered that the structural position of the focal firm moderates the administrative environmental innovation implementation–environmental disclosure, while Gualandris et al. (2021) investigated how the supply chain structure associates with transparency in the context of ESG. While the aforementioned studies have adopted an SNA approach, they have insufficiently differentiated between the various dimensions of sustainability (Alinaghian et al., 2020).

Regarding multi-tier sustainable supply chain management, previous research has identified and examined a number of supply chain configurations that are defined by the structural arrangement of actors and the linkages among them (Koberg and Longoni, 2019). Because of complex and global SCNs, companies are increasingly concerned about managing the sustainability of sub-suppliers and even the suppliers farthest upstream (Gong et al., 2018). However, with thousands of suppliers, the task may prove to be almost impossible (Meinlschmidt et al., 2018). In addition, previous research acknowledges that firms in a SCN are not equally exposed to stakeholder awareness and scrutiny. According to Schmidt et al. (2017), the more visible brand companies close to end-consumers face more immediate pressure to engage in sustainable business practices.

Global value chain (GVC) scholars have long recognized the need to understand governance structures of SCNs. They maintain that external conditions and pressures, such as private standards and requirements of global buyers and public governance, such as rules and regulations, facilitate the diffusion of global sustainability standards (Gereffi and Lee, 2016). Buying firms combine different governance mechanisms for managing the sustainability of their suppliers (Wilhelm and Villena, 2021). Mena et al. (2013) and Tachizawa and Wong (2014) recognized open, closed, third-party and "don't bother" supply chain configurations. In an open or indirect configuration, lead firms require their first-tier suppliers to implement the lead firm's sustainability requirements in their suppliers' operations (Wilhelm et al., 2016a). In a closed or direct configuration, the lead firm establishes direct contact with suppliers and lower-tier suppliers and attempts to manage their sustainability through formal or informal means (Koberg and Longoni, 2019; Tachizawa and Wong, 2014). However, this strategy is difficult to deploy because of the geographical dispersion of sub-suppliers and information on suppliers considered confidential (Wilhelm and Villena, 2021). The lead firm may also delegate responsibility to third parties, such as NGOs or standardization organizations, to provide training and assistance or to assess suppliers' performance (Tachizawa and Wong, 2014). The final governance option is "don't bother" where the buying firm has an internal or only first-tier supplier focus (Wilhelm et al., 2016b), which leaves suppliers considerable room in terms of how and to what extent sustainability is practiced (Sinkovics et al., 2021).

The above discussion suggests that approaches to sustainability are influenced by the structure of a firm's SCN. The literature on the structural characteristics also hints that network patterns and governance mechanisms may be deeply interlinked. For example, a closed configuration where lead firms bypass suppliers to create direct contact with sub-suppliers can create a highly centralized network position for the lead firm (Alinaghian et al., 2020). Yet, it remains largely unclear what the mechanisms are through which an SCN position may affect sustainability (Bellamy et al., 2020). Recent research indicates, for example, that less central and less powerful firms may be more likely to adopt a "don't bother" approach (Tachizawa and Wong, 2014), while a central position in the network enables a firm to deepen its commitment to sustainability and to broaden its scope of interactions (Vurro et al., 2009). Hence, the structure of the interactions among firms may facilitate or limit an individual firm's actions to manage sustainability issues (Vandchali et al., 2021). For example, central firms can control information flows, act as a gatekeeper, and bridge unconnected members (Vurro et al., 2009). If the member firms are tightly connected, informal governance mechanisms may work better, thereby reducing transaction costs (Tachizawa and Wong, 2014). As previous research on SCNs demonstrates, it is critical to understand how network structure influences both individual firms and the whole SCN. Traditionally, performance measurement in SCM has taken an internal perspective and paid little attention to external embeddedness (Seiler et al., 2020). While much of research has focused on how individual firms can improve their sustainability performance, firm-level approaches provide an incomplete view. An understanding of SCN structure is crucial because the formation of ties between different actors in the SCN can affect a firm's behavior, strategies and implementation of sustainable supply chain management (Vandchali et al., 2021). Hence, Alinaghian et al. (2020) call for future research to collect and construct real-world large-scale sustainable SCN datasets to investigate how network members achieve their sustainability goals across their supply chains. However, one of the challenges in sustainable supply chain management is measuring sustainability performance supply chain-wide (Schöggl et al., 2016). Investors increasingly rely on ESG ratings that are based on publicly available data, such as CSR reports (Gyönyörová et al., 2020), but researchers also suggest alternative methods to collect sustainability information across the supply chain using a more diverse set of indicators (Ahi and Searcy, 2015; Tajbakhsh and Hassini, 2015; Schöggl et al., 2016).

An overview of selected sustainability related studies is shown in Table 1. As shown in the table, there are many qualitative empirical studies and a relatively large number of conceptual studies (i.e., developing a conceptual framework to measure sustainability performance in SCN). However, the number of quantitative empirical studies is rather limited, especially on the network level. Data in previous studies on sustainability is primarily collected at the single-company or dyad level although the topic might be conceptually discussed on a supply chain or network level, both in SCM and GVC literature (Wahl and Bull, 2014; Alinaghian et al., 2020). Data collection and analysis of network-related data, however, is missing. Our research contributes to filling this research gap with empirical data on the SCN level combined with ESG data.

Table 1
Overview of selected sustainability-related studies in the supply chain management literature.

Study	Research approach	Scope, sample	Major findings
Ahi and Searcy (2015)	Structured content analysis	445 articles published up to the end of 2012	Identification of 2555 unique metrics that have been published in the literature on green and sustainable supply chain management (SSCM).
Alinaghian et al. (2020)	Systematic literature review	73 articles from 18 peer-reviewed journals published between 2000 and 2020	Identification of multiple node-level and network-level structural properties that play a role in supply chain sustainability.
Awaysheh and Klassen (2010)	Literature review and large-scale survey	Plant managers in three industries in Canada	Transparency and organizational distance in the supply chain are related to supplier socially sustainable practices.
Bellamy et al. (2020)	Network analysis	Multi-industry dataset of 3106 firm-year observations based on 67,809 dyadic cost-of-goods-sold-based relationships	Administrative environmental innovation implementations are positively associated with the extent of environmental disclosure and moderated by accessibility, control and interconnectedness.
Gualandris et al. (2021)	Network analysis	4803 firms and 20,504 contractual ties organized in 187 extended supply chains	Supply chain density associates positively and supply chain clustering negatively with supply chain transparency. Geographical heterogeneity positively associates with supply chain transparency.
Hyder et al. (2017)	Qualitative case studies	21 first- and second-tier suppliers in Bangladesh	Formal control is found to generate competence trust, whereas intentional trust is achieved through informal control.
Kauppi and Hannibal (2017)	Interviews and secondary material	Representatives from 10 different sustainability assessment initiatives	Social sustainability assessment initiatives act by instigating institutional pressures indirectly rather than directly.
Koberg and Longoni (2019)	Literature review	882 relevant papers published in the period ranging from 2003 to June 2018	Identification of multiple governance mechanisms and configurations as key elements of SSCM.
Leppelt et al. (2013)	Multiple-case study	5 supplier organizations in Central Europe	Effective marketing of CSR capabilities enhances a supplier's reputation only if it sends consistent signals to the market.
Marshall et al. (2015)	Literature review and survey	156 supply chain directors in Ireland	The research findings show theoretically sound constructs based on four underlying sustainable

(continued on next page)

Table 1 (*continued*)

Study	Research approach	Scope, sample	Major findings
			supply chain management practices.
Mathivathanan et al. (2018)	Literature review and survey	33 experienced personnel from the Indian automotive industries	Management commitment towards sustainability and the triple bottom line approach are the most influential practices for implementing SSCM.
Meqdadi et al. (2019)	Case study	Four case studies based on 38 semi-structured interviews	Coercive and non-coercive power impact suppliers' engagement in sustainability initiatives and its wider diffusion in supply networks.
Quarshie et al. (2016)	Systematic literature review	195 articles, published in 12 peer-reviewed journals from 2007 to 2013	There are highly complementary research topic areas but only limited synergy. The research area at large would benefit from greater integration.
Saunders et al. (2019)	Conceptual theory development	Conceptual analysis with illustrative case example	Development of a lens with which to view the influence of a firm's structural embeddedness in its organizational social network on developing, diffusing and adopting sustainability initiatives.
Schmidt et al. (2017)	Survey research	Cross-industry data of 284 firms utilizing primary and secondary data	The closer a company is located toward the end consumer, the higher its GSCM practice levels. Conversely, performance gains decrease with company proximity to the end consumer.
Siems et al. (2021)	Literature review	Analysis of 382 food and automotive papers published between 2002 and 2018	Food industry focus shifts from certification to stakeholder integration; Automotive industry from monitoring to joint product and process development.
Schöggl et al. (2016)	Literature review and expert workshops	Five focus group workshops with experts from the European automotive and electronics industry	Development of a conceptual framework for supply chain sustainability assessment (ASSC framework).
Tachizawa and Wong (2014)	Systematic literature review	Analysis of 39 studies and relevant theories	Identification of four approaches to manage the sustainability of multi-tier supply chains and related contingency variables and their effect on the proposed approaches.
Tajbakhsh and Hassini (2015)	Literature review	140 journal articles, cases and reports that appeared since 1994	The literature can be classified according to seven sustainability dimensions (economical, environmental, social, reputable, valuable, equitable and sustainable).
Tate et al. (2013)	Conceptual	Literature review on network theory and environmental sustainability followed by propositions development	Variation in the level of structural and relationship embeddedness affect network diffusion of environmental business practices differently.
Vurro et al. (2009)	Conceptual	Literature review followed by theoretical framework development (network level perspective)	Development of a sustainable supply chain governance (SSCG) model, resulting from combinations of supply chain network density and centrality of the focal organizations.
Wilhelm et al. (2016a, 2016b)	Case study	Seven cases of global multi-tier supply chains (MSCs) from four different industries.	Three main factors determine when and how buying firms actually extend their sustainability strategies to their sub-suppliers.

3. Methods

3.1. Data collection

In the first step, SCNs were identified using Bloomberg's SPLC-GO module. The network and financial data were retrieved from 2667 companies from different industries that (i) have manufacturing partnerships with suppliers and customers, (ii) have an industry revenue assigned by BICS larger than one hundred million, and (iii) are not assigned to the financial services industry according to the North American Industry Classification System (NAICS). The 2667 companies were accounted for as focal companies. Bloomberg's SPLC-GO was used to quantify the upstream and downstream supply chain relationships of a focal company (see Wetzel and Hofmann, 2019). The upstream and downstream supply chain partners with the strongest relationships to the focal companies, based on procurement and sales volume, were reported. A maximum of the five most important customers and suppliers were included. This sampling procedure reduces complexity but does not limit the value of the analysis as the relevance of the listed customers and suppliers in terms of the relationship amount drops sharply (Wetzel and Hofmann, 2019). Thus, all companies (supplier, focal company, customer) were added together for a total of 5458 unique companies with financial data over four different years, between 2015 and 2018, before the COVID-19 pandemic caused turbulence to SCNs and affected their operations.

In the second step, the Refinitiv Eikon database was used to collect ESG data from 2018. The database (formerly called Asset4) has been used for many articles (e.g., Duque-Grisales and Aguilera-Caracuel, 2021; Hartmann, 2021). While there are many providers of ESG ratings on the market, Refinitiv has one of the most comprehensive ESG data collections that is updated on a continuous basis (Refinitiv, 2022). Refinitiv Eikon publishes ESG data from verifiable, publicly available information sources to calculate 186 measures, which form 10 categories and subsequently three pillars (ESG); it covers more than 12,000 firms (Refinitiv, 2022). The ESG scores for the 10 main categories are also available on public domain and therefore facilitate replicability of the study. ESG data were available for 2905 companies in the SCN. The final SCN consisted of 5458 companies and 11,950 ties between companies. Tie strength was weighted using supplier dependency (% of supplier's total revenue generated in year 2018 with the respective focal company). Network analysis was conducted on the complete network data (N = 5458) while sustainability performance implications are analyzed only for those firms where ESG data was available (N = 2905). Industry composition of the sample, geographical division and number of upstream and downstream partners for focal firms are shown in Table 2.

3.2. Performance and network measures

Sustainability performance was measured via three variables calculated by Refinitiv, as follows: *ESG score* is an aggregate indicator consisting of a weighted sum of three pillar scores—environmental, social, and governance (ESG). It quantifies a firm's relative ESG performance across 10 main themes. *Environmental score* consists of three categories of resource use, environmental emissions, and environmental innovations. *Social score* consists of four categories of a safe and equal environment in the workforce, respect for fundamental human rights, commitment to being a good citizen (community), and the capacity to produce quality goods and services (product responsibility). *Governance score* includes three categories of corporate social responsibility (CSR) strategy, management, and shareholders' rights. In the network level, we measure collective sustainability performance to capture aggregate level. Following Gualandris et al. (2021), we calculate the percentage of members in each sub-cluster that have an above-median ESG value in the larger network after we have removed those network members who do not disclose any ESG information. Financial performance is measured as *return on assets* (ROA) score available at Bloomberg (e.g., Lanier et al., 2010).

We used a combination of node- (i.e., firm) and network-level metrics to evaluate the structural characteristics of a network (Wichmann and Kaufmann, 2016). While node-level metrics assess the embeddedness of a single firm in a network, network-level properties reflect the overall organization of the network connections (Alinaghian et al., 2020). The operationalization of the variables is shown in Table 3. *Network density* assesses the cohesion of the network (Carnovale and Yeniyurt, 2015; Wichmann and Kaufmann, 2016). A dense network promotes common norms and facilitates information transfer because of frequent interactions (Alinaghian et al., 2020; Su et al., 2020). *Network centralization* is used to measure the distribution of power across the network (Kim et al., 2011). *Centralization* evaluates the degree to which authority is concentrated around a few nodes in the network (Kim et al., 2011). *Assortativity* measures the extent to which firms associate with similar firms in the network, which may lead to greater mutual understanding (Su et al., 2020). We calculate assortativity in terms of sustainability, that is, if sustainable firms associate with other sustainable firms.

Concerning node-level metrics, the influential scope of a firm is captured by *degree*, which measures the number of direct partnerships of a firm—the higher the number of connections, the more central the role in the respective network (Kim et al., 2011). A firm's power in the network is measured as *eigenvector centrality* (Borgatti and Li, 2009). This reflects the ability of a firm to have connections with influential members in the network and to have access to various resources within the network (Han et al., 2020). *Closeness centrality* represents how close a firm is to other firms in the network. Firms with high closeness centrality can quickly interact with other firms in the network, and they tend to receive information through numerous intermediary actors (Wichmann and Kaufmann, 2016). *Betweenness centrality* is used to operationalize brokerage since it dictates the extent to which a firm acts as an intermediary between other network members (Borgatti and Li, 2009). A firm occupying a high betweenness position has the ability to control information flows and resources between non-adjacent network members (Alinaghian et al., 2020). *Bridging centrality* measures the ability of the firm to connect larger or more densely connected sub-regions with each other (Hwang et al., 2008). *Reach* measures how many other firms a focal firm can reach within a set number of steps (here 2), which implies the firm's ability to convey information (Adhikary et al., 2020).

3.3. Analysis methods

We followed an exploratory approach and aimed to identify novel patterns instead of testing existing frameworks. SNA was used to map and assess structures and relationships on the node and network levels using R package and Gephi. While automotive networks had already been investigated by applying SNA tools in the early-2000s (Choi and Hong, 2002), sustainability research in this context has mostly relied on case studies or survey research, which limits the ability to account for the interdependence among a large number of actors. Furthermore, we used a community detection algorithm to discover cohesive groups in our large-scale network. Communities are subgroups that are locally dense and separated to some degree from the rest of the network (Stoltenberg et al., 2019). We used the Girvan and Newman's (2002) edge-betweenness algorithm which is suitable for undirected graphs. The algorithm defines communities by iteratively removing edges (e.g., relationships between firms) that have a high likelihood of linking separate communities (Girvan and Newman, 2002). The GN algorithm continues until the entire network has been completely divided, and it is generally able to provide reliable solutions for medium-sized groups (Stoltenberg et al., 2019). The choice of the community detection method plays a role in the structure of the communities. It is noteworthy that in this method, each company is related to a single community. Given that the GN algorithm identifies edges carrying large numbers of shortest paths between pairs of nodes, the results reflect that companies with more transactions have greater weigh in the network.

Data sources and analysis methods are illustrated in Fig. 1.

4. Results

The results will be first discussed on a more general level of the whole dataset, before zooming into the automotive industry.

4.1. Node-level results of the whole dataset

At the node level, firms tend to score higher on the social and governance dimensions than on the environmental dimension, but there are large differences among the firms. On average, a firm is directly connected to four other firms (degree). Indirectly, they can reach on average 52 other firms in two steps. The vast majority of the firms (N = 3400) are linked to the network via a single connection. The low average value of eigenvector centrality suggests that only a small number of firms are connected to other high-profile firms.

To investigate the relationship between node-level network characteristics and sustainability performance (including ROA), a correlation analysis was performed on the key node-level variables (Table 4).

The results show that governance is less connected with structural characteristics than environmental and social performance. While all centrality measures seem to have a significant positive correlation with sustainability performance, degree, eigenvector, and betweenness centrality seem to have the strongest positive associations. The number of firms a firm can reach indirectly is also relatively strongly connected especially with environmental and social performance. ROA has a small positive correlation with environmental score, degree, eigenvector centrality, and reach.

4.2. Results of community detection

In the next step, we analyzed the network-level structural

Table 2
Industry break-down.

Industry sector		Number of firms
Manufacturing		2763
Information		367
Transportation and Warehousing		364
Construction		297
Professional, Scientific, and Technical Services		288
Utilities		286
Wholesale Trade		247
Retail Trade		226
Mining, Quarrying, and Oil and Gas Extraction		220
Administrative and Support and Waste Mgmt and Remediation		86
Finance and Insurance		86
Real Estate and Rental and Leasing		68
Accommodation and Food Services		60
Health Care and Social Assistance		36
Arts, Entertainment, and Recreation		22
Agriculture, Forestry, Fishing and Hunting		14
Educational Services		7
Other Services (except Public Administration)		7
N/A		14
Country of headquarters		
China		1195
USA		1015
Japan		834
Korea; Republic		325
Taiwan		238
India		160
United Kingdom		155
Hong Kong		116
Germany		111
Indonesia		106
France		102
Canada		88
Australia		72
Russia		69
Switzerland		62
Sweden		53
Malaysia		49
Italy		42
Brazil		42
Thailand		41
Mexico		39
Vietnam		34
Netherlands		32
South Africa		31
Singapore		29
Ireland		29
Spain		28
Philippines		26
Chile		25
Norway		22
Denmark		21
Finland		20
Turkey		19
Belgium		19
Bermuda		18
Saudi Arabia		18
Austria		16
Israel		15
New Zealand		15
Luxembourg		14
Others with $N \leq 10$		113
Number of partners for focal companies	**Upstream**	**Downstream**
0	611 (23%)	966 (36%)
1	382 (14%)	425 (16%)
2	303 (11%)	253 (9%)
3	206 (8%)	192 (7%)
4	271 (10%)	203 (8%)
5	894 (34%)	628 (24%)

Table 3
Variable operationalization.

Variable	Level	Explanation
Sustainability performance		
ESG score	Node	Overall company performance based on publicly reported data on environmental, social and corporate governance pillars (0–100)
Environmental score	Node	Environmental performance based on resource use, emissions and innovation (0–100)
Social score	Node	Social performance based on workforce, human rights, community and product responsibility (0–100)
Governance score	Node	Governance performance based on CSR strategy, management and shareholders (0–100)
Financial performance		
Return on Assets (ROA)	Node	Net income/Total assets
Structural characteristics of the network		
Network density	Network	Total edges (ties)/Total possible edges (ties)
Network centralization	Network	The overall connectedness around particular nodes in a network
Assortativity	Network	The tendency of nodes being connected to nodes with similar properties in a complex network
Degree centrality	Node	How many direct connections each node has to other nodes in the network
Eigenvector centrality	Node	A node's importance while taking into account the importance of its neighboring nodes.
Closeness centrality	Node	Sum of the length of the shortest paths between the node and all other nodes in the network
Betweenness centrality	Node	The extent to which a node falls on the shortest paths between other nodes
Bridging centrality	Node	The extent to which a node connects sub-regions of the network
Reach (2-step)	Node	Number of nodes in the network that the focal node can reach in a given number of steps

characteristics. Specifically, to gain a better understanding of the different communities or clusters within the data, we used community detection. As a result, 681 clusters emerged. Modularity measures the proportion of intra-community ties compared to those expected in a random network (Stoltenberg et al., 2019). The modularity value of this solution was 0.64, which indicates a network with a high community structure (Girvan and Newman, 2002).

A total of 79% of the clusters were very small, consisting of 1–5 members; 16% contained 6–20 members, and 4% contained 21–100 members. There were altogether seven clusters with more than 100 member firms. Table 5 shows the four largest clusters—automotive, electronics, fast moving consumer goods (FMCG), and aerospace. In addition to network characteristics, the table also shows the five most and least central firms and their ESG scores for each cluster. The majority of the central firms have excellent ESG performance (ESG score > 75). This further corroborates the earlier finding that central firms seem to be able to achieve higher ESG scores than their less connected counterparts.

The largest clusters have a low density but relatively high centralization, which means that the clusters are organized around a few powerful core firms, but, overall, they are not very cohesive. Many firms in the periphery of the network are connected to the core firms but not with each other. Hence, there are likely to be several communities within each industry.

To further deepen the analysis, we examined the automotive cluster in more detail.

4.3. Analysis of the automotive network

The automotive cluster was further divided into 61 sub-clusters using the community detection methods described earlier. Fig. 2 below shows the network structure and the largest sub-clusters in the automotive

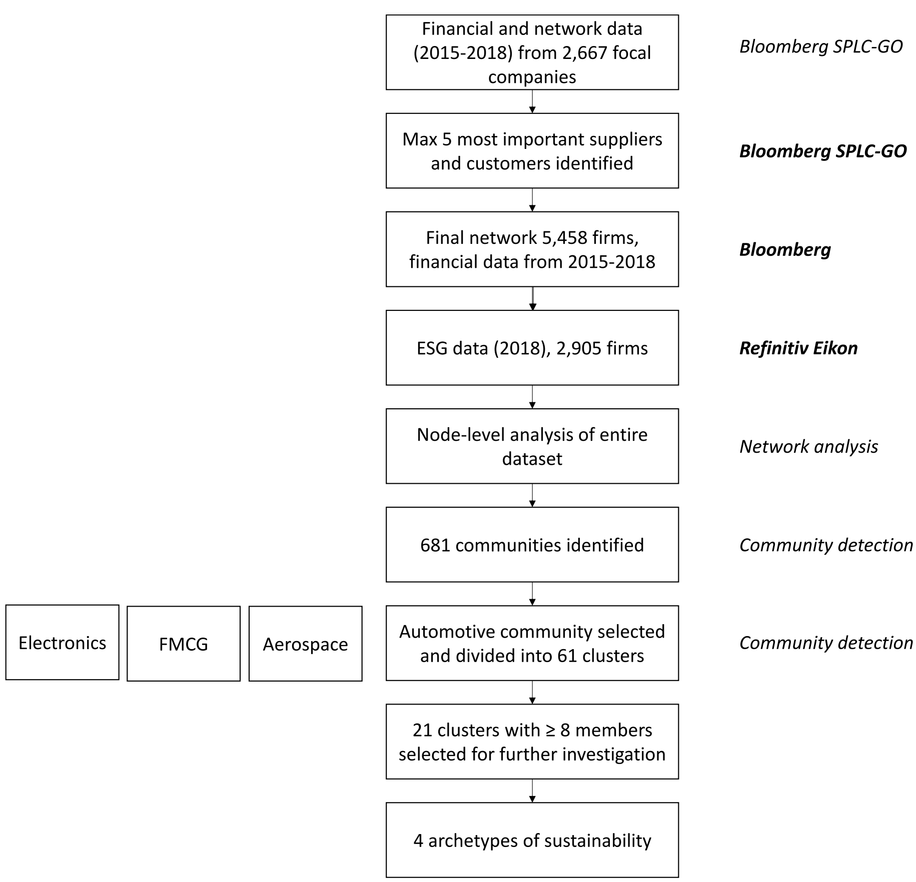

Fig. 1. Data sources and analysis methods.

Table 4
Descriptive statistics and Pearson correlations coefficients of node-level metrics.

Variable	Mean	St. Dev.	ESG score	Env. score	Social score	Gov. score	ROA	Degree centrality	Eigenvector centrality	Betweenness centrality	Bridging centrality	Reach (2-step)
ESG score	50.86	21.05	1.000	0.846**	0.870**	0.595**	0.051**	0.294**	0.292**	0.256**	0.088**	0.354**
Environmental score	45.44	28.03		1.000	0.740**	0.368**	0.069**	0.286**	0.283**	0.227**	0.094**	0.337**
Social score	52.17	24.59			1.000	0.395**	0.023	0.242**	0.241**	0.206**	0.078**	0.308**
Governance score	55.27	22.01				1.000	0.044	0.178**	0.169**	0.149**	0.098**	0.197**
Return on Assets (ROA)	3.70	15.70					1.000	0.062**	0.064**	0.034	0.038	0.075**
Degree centrality	4.38	7.05						1.000	0.999**	0.450**	0.071**	0.805**
Eigenvector centrality	0.03	0.05							1.000	0.451**	0.089**	0.804**
Closeness centrality	0.259	0.10								0.302**	0.107**	0.468**
Betweenness centrality	0.006	0.02								1.000	0.116**	0.673**
Bridging centrality	<0.001	0.001									1.000	0.200**
Reach (2-step)	52	81.27										1.000

Table 5
Four largest clusters of firms.

	Automotive cluster	Electronics cluster	FMCG cluster	Aerospace cluster
Number of firms	604	529	486	358
Number of ties	1497	1073	1231	907
Network density	0.008	0.008	0.010	0.014
Network centralization	0.254	0.297	0.293	0.311
Most central firms (ESG total score in parentheses)	Volkswagen (83.59) Ford Motor (87.40) Toyota Motor (76.51) Daimler (92.12) Fiat Chrysler (90.28)	Samsung (90.11) Apple (79.04) LG Electronics (89.72) Best Buy (87.71) Sony (84.84)	Walmart (82.38) Nestlé (91.01) Unilever (91.83) Alphabet (62.98) Alibaba (36.35)	Boeing (80.29) Airbus (82.21) United Technologies (NA) General Electric (83.00) Safran (53.95)
Least central firms (ESG total score in parentheses)	Canadian Pacific Railway (71.54) Jiangxi Copper (43.81) SMC Corp (47.28) Petrofac (63.54) Gmexico Transportes (45.61)	Bel Fuse (38.87) Kellogg (80.29) Varian Medical Systems (53.47) Ultra Clean Holdings (31.33) Ashtead Group (44.55)	Luz del Sur (18.29) Avis Capital (24.13) Fraser & Neave (64.25) Super Group (37.33) Gaztransport Technigas (60.26)	Sunrise Communications (30.70) RIB Software (18.92) Tata Power Company (62.85) Stratasys (24.04) Poste Italiane (78.40)

cluster and also illustrates the total ESG score of the companies, supporting again the positive correlation between centrality measures and sustainability performance. In the figure, the larger the size of the node, the more central the firm is in the network. Most central firms are colored blue, which represents a high sustainability score. Interestingly, the assortativity of the ESG score was −0,085, meaning that, in general, sustainable firms do not associate with other sustainable firms.

21 sub-clusters with eight or more members were selected for a detailed examination. The largest cluster (60) consists of 154 companies. Most of the well-known original equipment manufacturers (OEMs), such as Volkswagen, Toyota, General Motors, Fiat-Chrysler, Daimler, and Ford, belong to this group. The group also contains many suppliers of auto parts, including Magna International, Aisin Seiki, and Denso Corporation, for example. There are also medium-sized clusters focused around Kia and Hyundai (17), Caterpillar (39), and the steel and mining company Arcelormittal (20). It should be noted that the automotive ecosystem also includes organizations that can be considered secondary members, such as logistics service providers. These firms are not directly part of the automotive production, but they still play an important role in the automotive ecosystem. Table 6 summarizes the key characteristics of the largest sub-clusters.

While the density of the complete automotive network was below 0.01, the densities of most sub-clusters exceeded 0.10 and therefore exhibit moderate cohesion. Most dense sub-clusters (44, 54) exceeded 0.30. Geographical proximity does not seem to be a necessity for tight network connections, as demonstrated by the global coverage of sub-cluster 54. However, sub-cluster 54 is highly centralized around engine and generator producer Cummins. Other highly centralized sub-clusters include 16 (Atlas Copco: compressors), 22 (NHK Spring: springs), and 43 (SKF: bearings and seals). In these sub-clusters, authority is concentrated around the central firm, which is well-connected to other firms, but the other firms are not well-connected to each other. As network centralization reflects the distribution of power or control (Kim et al., 2011), most sub-clusters seem to have a concentrated power structure.

In most of the sub-clusters 50% or close to 50% of the firms reach above-median ESG values, but there are also notable exceptions, as in sub-clusters 4, 19 and 22 none of the firms reach above-median scores and in sub-clusters 41 and 44 less than 25% reach above-median scores.

Overall, four archetypes of sustainability along a continuum of environmental and social sustainability dimensions emerged from our data, shown in Fig. 3a and elaborated below. Fig. 3b shows the centralization vs. density matrix.

4.4. Archetypes of sustainability

The first archetype that emerged from the data is labeled *impassive networks* and includes clusters that score low both in terms of

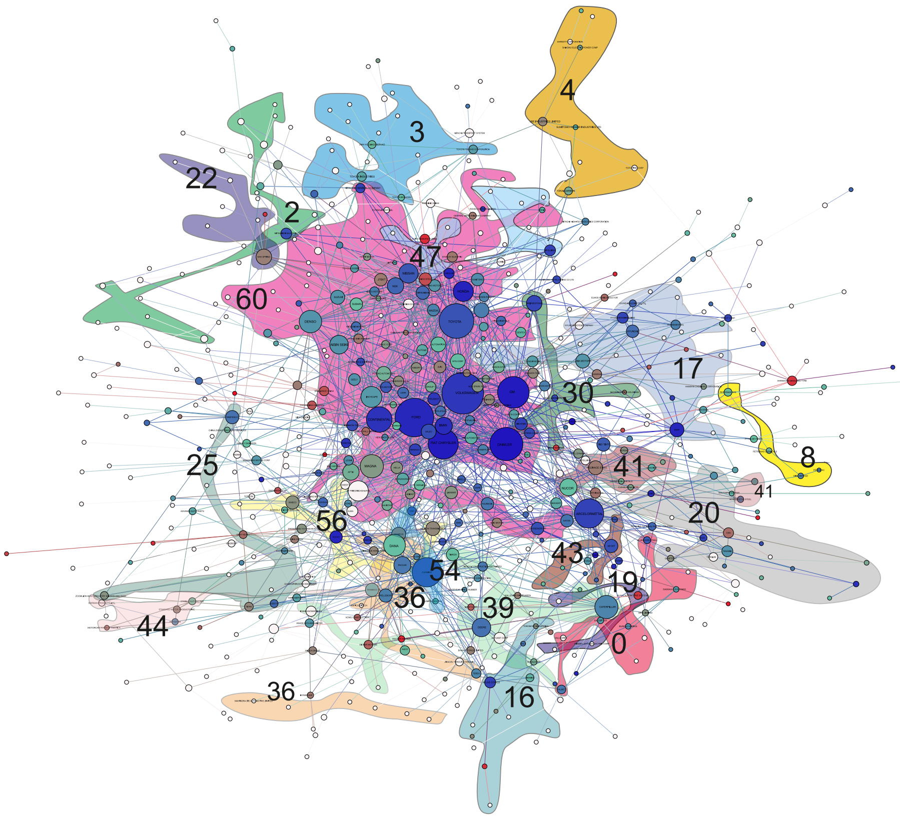

Fig. 2. Automotive network with sub-clusters and ESG scores. RED: low value of ESG score; BLUE: high value of ESG score; GREEN mid value of ESG score; WHITE: no ESG data available. The larger the size of the node, the more central the firm.

environmental and social sustainability (Fig. 3). The governance scores tend to be on a higher level (Table 6). Interestingly, all impassive networks are located in the upper right corner of Fig. 3b with high centralization and high density. It implies that if the network is in the hands of one or a few powerful members and they are not using (or are misusing) power to promote sustainable practices, other network members may also remain impassive. The lowest performing clusters (22 and 19) produce auto parts, springs, cutting tools, and thermal management and are among the least profitable. Clusters 4 and 41 are profitable clusters operating industries burdened by a heavy environmental footprint (Sauer and Seuring, 2017). Cluster 44 mostly specializes in producing replacement parts and cluster 36 produces drivetrain. A lack of consumer pressure may be common for these clusters as they operate in the upstream, making their brand less visible to consumers and media. Such a position can demotivate firms from developing sustainable practices (Schmidt et al., 2017). Interestingly, most firms in this archetype reach a low number of other firms, which may imply that they do not have good access to information provided by other firms (Carnovale and Yeniyurt, 2015).

The second archetype is labeled *orchestrated networks.* While many clusters could be placed in this quadrant, most of them are medium performers. A notable exception is cluster 47, that is characterized by vertical integration. Although the cluster is not heavily centralized, vertical integration enables closer monitoring, facilitates information exchange, and aligns incentives between the parent company and subsidiary (Zhou and Wan, 2017). Korean-based cluster 17 is focused around Kia Motors suggests that geographical proximity may promote reaching high sustainability performance. Most sub-clusters have a quite high reach in the network but they are not very dense. Cluster 54 that is close to belonging to orchestrated networks is an interesting exception with high density and high centralization. Firms may use these properties to orchestrate internal and external resources for proactive sustainable initiatives in their SCNs (Gong et al., 2018). Optimally, this leads to a win-win situation where the central firm is able to leverage its highly sustainable SCN to boost its own performance while the suppliers are able to build sustainability capacity and diffuse the practices to their sub-suppliers.

The third archetype contains *socially focused networks*. These networks tend not to be very dense but there is a notable degree of centralization in clusters 16 and 43 concentrated around Caterpillar and SKF. Here network centralization works in favor of sustainability. If the most central firm is highly committed to sustainability, it can facilitate the diffusion of sustainability throughout its network. In the oil and gas cluster 8, the business model is problematic because of the extraction of non-renewable fuels. In terms of social indicators, the oil and gas industry has been claimed as superior to others (Hadi and Baskaran, 2021). However, it may be merely a way of evading responsibility for addressing climate change (Ferns et al., 2019). Cluster 30 focuses on tires or rubber, which may ultimately cause the destruction of tropical forests to make way for rubber plantations. Clusters 8 and 30 could be said to have a common denominator, namely an inherently non-environmental business model. Yet, all sub-clusters are close to belonging to the orchestrated networks quadrant, and especially in the tire cluster, the leading companies are already there. Their good social performance may be a result of the network structure. The betweenness centrality in cluster 30 is high, implying that these firms work with a large number of other actors. Good access to sustainable suppliers, for example, can yield significant benefits, such as knowledge spillovers. Cluster 8, in turn, demonstrates high bridging centrality. Therefore, this group includes firms that act as global bridges connecting otherwise disconnected parts in the network, and allow them to get access to each other's information or knowledge.

The fourth archetype is labeled *environmentally focused networks.* Intuitively, it may be easier to integrate social sustainability into business operations compared to changing the whole business model, as in the socially focused networks discussed earlier. However, while the

Table 6
Largest automotive sub-clusters and their key characteristics.

All sub-clusters within the automotive network with N ≥ 8					Network level metrics		Node-level metrics (mean)									
Sub-cluster	N	Description	Main area	Most central firm	Network centralization	Network density	Degree centrality	Eigenvector centrality	Betweenness centrality	Closeness centrality	Bridging centrality *	Reach (2-step)	Employees	Environmental Score	Social Score	Agg. ROA
0	17	Steel products; solution providers (software etc.)	Global	Bluescope Steel	0.412	0.118	1.882	0.010	488.979	0.221	0.352	59.176	15,803	50.887	53.622	5.573
2	16	Electric equipment	Japan	Mitsubishi Electric	0.426	0.125	1.875	0.003	577.138	0.214	0.494	50.812	38,514	61.493	40.660	5.594
3	14	Toyota subsidiaries and partners	Japan	Toyota Industries	0.330	0.165	2.143	0.020	444.233	0.227	0.257	40.714	11,719	77.346	52.846	2.652
4	9	Rubber; plastics; basic chemicals	Japan	Tokai Carbon	0.416	0.250	2.000	0.009	687.569	0.205	0.609	53.889	8872	50.708	40.804	5.595
8	8	Oil and gas	Malaysia	Petronas Gas	0.314	0.250	1.875	0.011	582.527	0.211	1.152	54.250	39,721	44.487	59.587	5.216
16	11	Air compressors, Caterpillar dealers	Global	Atlas Copco	0.692	0.182	2.000	0.022	534.292	0.230	0.461	76.364	6421	46.824	49.966	7.236
17	29	Kia and Hyundai	Korea	Kia Motors	0.366	0.106	2.862	0.043	879.963	0.240	0.302	64.828	35,845	57.459	57.686	2.083
19	9	Auto parts	China	Huayu Automotive Systems	0.565	0.222	1.778	0.003	485.037	0.228	0.103	27.333	9804	N/A	N/A	3.122
20	26	Iron and steel	Global	Arcelormittal	0.418	0.102	3.240	0.046	1007.387	0.234	0.338	81.462	34,781	56.617	65.207	6.646
22	10	Springs, thermal management, cutting tools	Japan	NHK Spring	0.759	0.200	1.900	0.026	793.837	0.239	0.558	39.8000	4438	21.958	23.338	2.484
25	16	Industrial machinery; tyres and rubber	Global	Nabtesco	0.427	0.142	2.437	0.019	475.758	0.233	0.415	56.563	15,716	46.341	47.641	4.344
30	15	Tyres; wiring and mining	Global	Bridgestone	0.393	0.162	3.200	0.053	1353.358	0.248	0.459	79.733	37,424	45.418	54.526	6.805
36	22	Drivetrain; industrial machinery	Global	Dana	0.321	0.104	2.773	0.041	907.033	0.246	0.214	71.454	13,904	46.904	53.437	6.599
39	32	Agriculture; construction and mining machinery	USA, India	Caterpillar	0.470	0.089	2.812	0.046	804.271	0.252	0.385	95.094	27,716	53.039	58.792	5.497
41	14	Iron and steel products; mining	USA, Russia	Nucor	0.409	0.209	4.357	0.082	761.595	0.258	0.317	113.571	18,343	33.875	44.865	12.815
43	10	Bearing and seal; coating	Global	AB SKF	0.659	0.200	3.000	0.046	549.531	0.242	0.191	100.300	22,805	59.98	63.59	0.834
44	11	Replacement parts	USA	Tenneco	0.425	0.309	3.545	0.034	539.357	0.239	0.419	43.455	13,444	29.417	46.216	8.025
47	11	Steel manufacturing; components	Japan and Korea	Daido Steel	0.392	0.218	3.091	0.045	872.908	0.251	0.331	101.546	24,474	73.376	64.484	2.404
54	9	Engines; generators; commercial vehicles	USA, EU, China	Cummins	0.614	0.306	7.222	0.133	2070.098	0.283	0.507	163.222	37,331	53.670	59.090	5.145
56	16	Transmission; vehicles; supporting technologies	Global	Paccar	0.500	0.158	3.812	0.065	940.221	0.262	0.306	86.375	15,967	59.478	60.086	6.988
60	154	OEM vehicle manufacturers; vehicle parts	Global	Volkswagen	0.334	0.040	6.331	0.158	1639.020	0.273	0.408	125.539	42,486	56.556	55.685	3.788

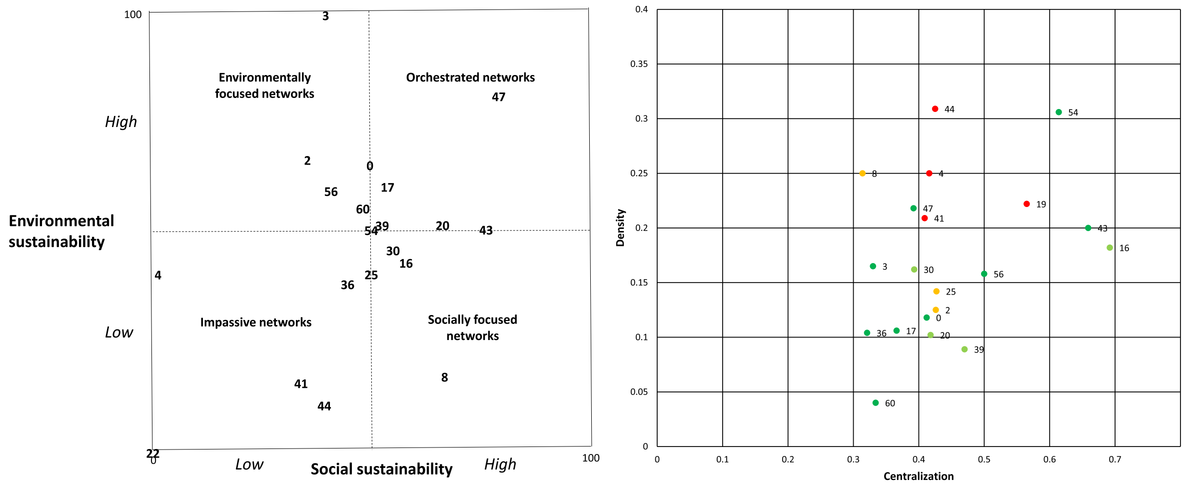

Fig. 3. Archetypes of sustainability (dark green: equal or larger to 50%; light green: 40–50%, orange: 30–40%, red: below 30% of the firms in the cluster performing better than the median).

health and safety of a firm's own employees have been high on the agenda for a long time, it has often been proven difficult to incorporate all social aspects into actual corporate policies and practices (Villena et al., 2021). Cluster 3 has the best environmental performance in this archetype. The cluster consists of Toyota subsidiaries and their partners, implying again that vertical integration facilitates high sustainability performance. Particularly cluster 60 demonstrate high centrality value (Fig. 3b), implying that these sub-clusters contain important nodes that are well-positioned and enjoy great control over information and resources (Alinaghian et al., 2020). The majority of OEM car manufacturers are also in this quadrant. Consumers expect that these well-known brands govern the sustainability of the whole SCN (Hartmann and Moeller, 2014). However, even these central firms have not been able to reach high collective sustainability performance on the network level and move to the orchestrated archetype.

Of note, there does not seem to be a clear pattern between sustainable and financial performance. For example, orchestrated networks 3 and 47 have low ROA if the whole cluster is measured as an entity, following Lanier et al. (2010). Out of the impassive networks, cluster 41 reaches a high ROA value, while 22 does not. Based on the earlier correlation matrix, it seems that while there might be a small positive correlation between node-level sustainability and ROA, sustainability is difficult to turn into a source of financial benefit on the network level.

5. Discussion

5.1. Implications for theory

The results reveal that although the central firms in the network tend to perform well, the SCNs are not yet sustainable. At the node level, our findings suggest that SCNs achieve different levels of sustainability depending on the patterns between supply chain members. In contrast to previous research suggesting that companies closest to the consumer interface tend to reach the highest levels of sustainable practices (Bellamy et al., 2020; Schmidt et al., 2017), our findings suggest that centrality is a better predictor. Many well-known consumer brands have high sustainability performance, but so also do many upstream companies. What is common to these companies is that they occupy high centrality positions in the SCN. More specifically, the number of direct and indirect contacts, especially with other influential members, facilitates sustainable practices. In addition, being located between actors that would otherwise be disconnected is beneficial. Closeness and bridging centrality also have a positive but smaller association to sustainability on the node level. Therefore, central firms are able to leverage their SCN for additional resources or information to realize sustainable performance benefits. However, at the moment, as our further analysis shows, it is very rarely extended to the entire network. This finding might also suggest that some central companies "outsource" unsustainable parts of the business to suppliers.

At the network level, we focused on companies belonging to the ecosystem of the automotive industry and used a community detection algorithm to divide it into smaller clusters of firms connected through supply chain ties. While community detection has been rarely used in SCM research, it proved to be a valuable approach to identify inter-firm linkages within larger SCNs.

Across the largest automotive clusters, four archetypes of sustainability emerged, which we termed impassive networks, environmentally focused networks, socially focused networks, and orchestrated networks (Table 7). However, none of the clusters, even within the orchestrated networks, reached excellent sustainability performance at the network level. Although the archetypes illustrate typical patterns, we might speculate as to which one companies could choose under certain conditions. Orchestrated networks would be a choice for a strong central firm with brand name and customer and stock market pressures in place. Environmentally and socially focused networks are short- and mid-term solutions, not a long-term option. Impassive networks are the unfortunate outcome when there is not enough market pressure or visibility and the regulatory framework is not enforcing high levels of sustainability.

Several interesting patterns emerged from the analysis of the network structural characteristics. Firstly, previous research has proposed that the degree of sustainable performance depends on the industry context (Tachizawa and Wong, 2014). In the automotive industry, different stages face different types of sustainability risks. For example, materials extraction may contribute to human rights violations (Hofmann et al., 2018). Xu et al. (2019) concluded that engine manufacturing had the highest environmental risk due to the manufacturing processes of cast iron and aluminum alloys, while assembly stage had the highest social risk. We also found that impassive networks were typically industries with a heavy environmental footprint, such as iron and steel production and mining. The socially focused networks may also be locked-in with an unsustainable business model, such as in the oil and gas industry. If these lead firms' reconfigure their business model, the effects may cascade throughout the SCNs when they form alliances with new customers and suppliers (Evans et al., 2017). While environmental reporting requires companies to collect measurable data, social reporting relies more on qualitative indicators (Wan Ahmad et al., 2016). Therefore, it may be easier to achieve higher social performance in many industries. Although in the node-level analysis we noticed that closeness to the end-consumer might not be the most decisive factor for the level of sustainable practices, the analysis of the

Table 7
Key characteristics and implications for sustainability archetypes.

	Impassive networks	Environmentally focused networks	Socially focused networks	Orchestrated networks
Key characteristics	High network centralization with unsustainable lead firm Heavy environmental footprint Lack of consumer pressure	High levels of environmental reporting High bridging centrality High betweenness centrality Vertical integration	High levels of social reporting Heavy environmental footprint	Central firm with high sustainability performance Vertical integration Geographical proximity High network centralization with a sustainable lead firm High betweenness and reach Low density
Network level implications	Since information and resource flows in highly centralized networks are controlled by the most powerful organization, the diffusion of sustainable practices is limited	Leaders' role in bridging different clusters to diffuse information and practices	If the lead firms changes the business model, the network needs to change significantly	High transparency needed, new technologies may provide solutions
Strategy options for lead firms	Use geographical differences for an advantage It may be easier to improve the social side	Take leadership Identify weakest links in the network Disclose more social information Improve collaboration with suppliers, do not simply impose standards	High risk option of business model re-configuration (long-term) Product changes (more sustainable production) Identify weakest links in the network	How to make money out of sustainability? Sustainability as a necessary but not a sufficient condition Identify central suppliers for a ripple effect Cost and revenue sharing and other incentives for suppliers
Suggested supply chain configuration	Don't bother (reactive)/ Closed (proactive)	Closed/ 3rd party	Open/ 3rd party	Open/ 3rd party
Strategy options for SME suppliers	No incentive from the lead firms Comply to regulations	Double agency role Improve social reporting	Improve products to attract new customers Double agency role Fulfill environmental regulations	Knowledge and technology transfer Attract new customers
Role of regulation	Need for enforced regulation, investments, taxation and pricing	High level of environmental regulation in place Increase level of social regulation	Heavy environmental regulation needed Support green R&D	Supply chain due diligence laws to encourage diffusion whole network

four sustainability archetypes hints that collectively, impassive networks tend to lack direct consumer pressure, which may decrease their motivation to disclose their environmental and social impacts (Bellamy et al., 2020).

Some of the sustainability challenges can be attributed to the focal firm's lack of power (Tachizawa and Wong, 2014), but in our automotive sample, impassive networks were rather centralized and dense. Therefore, focal firms should have a sufficiently powerful position to influence the SCN (Hofmann et al., 2018). The results imply that if a network is highly centralized but the central firm has a reactive approach to sustainable supply chain management, the whole network is likely to be reactive. Accordingly, the need for mandatory supply chain due diligence regulation has been justified with the argument that voluntary sustainability initiatives have failed to solve problems (European Parliament Resolution, 2022). Mandatory due diligence regulation, such as those put forward in the EU area, has a great potential to accelerate the sustainability transition, especially in high pollution industries. However, varying levels of regulation in global SCNs creates additional complexity (Villena and Gioia, 2018). One or perhaps even the only effective way to activate impassive networks might be mandatory regulation that coerces reactive focal firms to engage in sustainable supply chain management and push the due diligence upstream (Hofmann et al., 2018).

While previous results suggest that density enables information sharing and the development of common norms among network members (Gualandris et al., 2021), our results imply that dense ties across the SCN do not guarantee the development of a collectively high level of sustainability. This may be because dense networks increase coordination and the management effort from the lead firm (Tachizawa and Wong, 2014). If there is no reciprocity and trust, even a dense network lacks the ability to diffuse sustainable supply chain management practices efficiently (Tate et al., 2013). The "paradox of embeddedness" may derail performance by insulating firms from novel information beyond their existing network (Uzzi, 1997).

If central actors have taken a proactive approach to sustainable supply chain management, it manifested itself in excellent sustainability performance. The results revealed that vertical integration facilitates high collective sustainability outcomes. Murcia et al. (2021) recently demonstrated that firms with high sustainability performance tend to vertically integrate more (or outsource less) to increase control over operations and to reduce monitoring costs. Vertical integration, therefore, helps firms to align sustainability goals and practices among network members. Our results also propose that if the firm or the network has a role as a connector between other firms, it is able to achieve higher sustainability performance. High betweenness positions are often taken by first-tier suppliers that play a double agency role in channeling the lead firm's requirements further upstream (Wilhelm et al., 2016a). For the lead firm, identifying network members that occupy high centrality positions helps them identify the best candidates to diffuse sustainable supply chain management practices efficiently in the SCN. Network orchestration calls for systems that promote high levels of transparency and visibility across the SCN (Choi et al., 2021). Blockchain technology, for example, is showing promise for easing some of these issues (Kusi-Sarpong et al., 2022).

Furthermore, as the geographical and cultural distance increases, a part of the SCN vanishes behind the horizon. Our observations also support that geographical proximity is positively associated with network-level sustainability outcomes, especially if the cluster of firms is located in a region with high supply chain regulatory pressure, as also suggested by Gualandris et al. (2021). On the contrary, spatial complexity increases information asymmetries and uncertainties because of different legislative systems, cultures, languages, and ways of working (Tachizawa and Wong, 2014).

While there was a small positive correlation between environmental sustainability and ROA at the node level, this linkage does not seem to depend on network structural characteristics. Although we found that more central firms are able to achieve higher levels of sustainability, these firms and their networks are not able to turn it into enhanced profitability for all network members. A key challenge especially for the orchestrated networks then is how to make money out of sustainability. As the market may penalize firms having a low level of sustainability (Lourenço et al., 2012), it is proposed that sustainability is a necessary but not a sufficient condition. Creating truly sustainable SCNs often requires not only changes that produce win-win outcomes but also changes that inevitably force tradeoffs (Montabon et al., 2016).

Finally, our findings also raise questions about performance measurement. As advocated by Alinaghian et al. (2020), we separated sustainability into environmental, social, and governance (ESG) performance, thereby providing a more granular understanding of SCN structure and sustainability. The current measures of sustainability mainly assess how well firms communicate sustainability issues rather than how well they actually perform. As Clementino and Perkins (2021) point out, many firms respond to ESG ratings by improving disclosures, not the underlying actions. For example, a firm that has outsourced its delivery system looks better in terms of the use of fossil fuels although it may not make any effort to cut the carbon footprint of its suppliers. Hence, sustainability reporting does not necessarily entail actual commitment (Meehan and Pinnington, 2021), especially throughout the SCN. As our focus was not to identify best sustainability measures, it provides a natural path for future research. Supply chain finance and resilience scholars have already started to argue that performance measurement should incorporate a network perspective (e.g., Li and Zobel, 2020; Wetzel and Hofmann, 2019). The sustainable supply chain management literature should follow the lead. Developing objective network measures of sustainability may help address questions such as where in the network the weakest links are in terms of sustainability, and where the sustainability initiatives should be targeted to address those weaknesses. Moreover, sustainable supply chain management research can borrow measures from SNA to understand what roles structural foundations for concepts such as power, complexity and cohesion play to complement the more traditional research on the relational value of supply chain relationships.

To conclude, we add to the sustainable supply chain management field by combining node- and network-level perspectives to offer deeper understanding of, on the one hand, how the embeddedness of a firm in a network affects its sustainability, and, on the other hand, how the structural characteristics of the network affect overall sustainability of the network. As a methodological contribution, we advocate the use of network-level empirical evidence based on known transactional flows instead of relying on data collected at the single-company or dyad level. Overall, our findings suggest that SCNs act as co-determinants of firms' sustainability. Hence, there is a need for future sustainable supply chain management research to provide a more integrative view by developing network-based conceptualizations and measures of sustainability.

5.2. Implications for policy and practice

Our study makes several practical contributions. We focus on three stakeholder groups that can benefit from our results—large central firms, non-central SME suppliers, and regulatory authorities. Table 7 summarizes these implications.

If a firm in an impassive or socially focused network wants to improve its sustainability performance, it may be easier to start with social sustainability compared to changing to a greener business model. In the long-term, socially focused networks, such as the oil and gas industry, have a high-risk option of changing the way they create, deliver, and capture value. In the short term, firms can make changes to the products or processes. For example, many oil and gas companies have started to provide renewable energy options, especially as a response to normative pressures (Hartmann et al., 2021). Reactive firms may use regulatory differences to evade responsibilities, while more proactive firms significantly exceed regulatory compliance, which might be a competitive weapon if the market rewards such behavior. Increased reporting requirements, such as the proposed EU CSR due diligence directive, and even trade barriers in the form of taxes and customs might be needed to add economic incentives.

A key question for managers is to define how far it is possible to manage sustainability. While some firms might be able to purposefully design and manage a sustainable network, many other firms can benefit from belonging to one. To achieve high SCN-wide sustainable performance, we encourage supply chain managers to map their SCNs and consider their configuration. As vertical integration seemed to relate to higher sustainability performance, a closed configuration characterized by direct contacts with suppliers and sub-suppliers may work particularly well in complex situations and social aspects (Koberg and Longoni, 2019; Mena et al., 2013). Hence, especially environmentally focused networks may benefit from a closed configuration to be able to move to orchestrated networks. Lead firms with a large number of network members are more likely to delegate responsibility to a third party (Koberg and Longoni, 2019).

An open configuration, where the lead firm works only with first-tier suppliers, is more effective for environmental outcomes and appropriate when there is a low number of suppliers and the suppliers exhibit high sustainability capabilities (Wilhelm et al., 2016b; Koberg and Longoni, 2019). Hence, an open configuration is likely to work best in small orchestrated networks or environmentally-focused networks. Previous research advocates collaboration, incentives and profit-sharing over assessment-based approaches (e.g., Awaysheh and Klassen, 2010; Govindan et al., 2021). It might also be necessary to make structural changes to the SCN, such as terminate supplier relationships due to non-compliance (Bellamy et al., 2020).

In impassive networks, there may not be incentive for first-tier suppliers to transmit sustainability requirements further upstream because the lead firm does not drive development, unless regulation stipulates a higher level (Soytas et al., 2019). Without strict regulation and enforcement, it may be enough to convey a good impression of sustainability with ambiguous language and to normalize existing practices as sufficient (Meehan and Pinnington, 2021). This, of course, hinders changes to actual practices. Hence, policymakers should introduce additional regulation and greater enforcement. The most effective way seems to be targeting the most central firms as they have the power to cause a ripple effect.

Finally, the results also provide insights for smaller suppliers. SMEs may contribute significantly to sustainability through standard-setting and standard-adopting (Sinkovics et al., 2021). As SME suppliers may be short on sustainability resources and skills, they may benefit from the transfer of knowledge and technology within their SCN. Especially in networks where the environmental performance is not up to par with social sustainability, SMEs can leverage their SCN and improve their product to attract new customers. Since SME suppliers lack the bargaining power, they need to rely on trust and reciprocal relationships to manage their upstream (Wu, 2017).

5.3. Limitations and future research

Firstly, since our investigation of the structural characteristics of the four sustainability archetypes is exploratory, there may be potentially several different network configurations within each archetype. A direction for further research may thus be to use structural characteristic variables to generate the clusters and then assess their sustainability performance. While SNA provides a methodological framework, from a content-related perspective, it should be applied to supply chains with caution. The present study is based on an undirected network. Because it may be typical that sustainability propagates upstream, the network could be extended into a directed one. As suggested by Saunders et al. (2019), future research could investigate how variables measuring network characteristics, such as the power of nodes or tie strength, change during the implementation process of sustainability initiatives. Another limitation arises from the fact that we identified SCNs and clusters of firms using a community detection algorithm. A limitation of this approach is that a broader supply chain may be decomposed into multiple clusters. Recent research suggests alternative methods to isolate extended supply chains from data (e.g., Gualandris et al., 2021). Future research could apply these methods and compare the findings to further investigate the effects of structural characteristics on sustainability and other outcomes. It should also be noted that the clusters we investigated in more detail were embedded in the broader automotive SCN, which may affect the results. For example, many car manufacturers employ just-in-time systems, which requires tight coordination among suppliers (Wiedmer et al., 2021). Some of the findings, such as that central firms have a higher sustainability performance, were supported through the entire sample. Therefore, while the automotive industry is one the most influential and widely studied, we recommend that future research extend the in-depth analysis to other industries to test the generalizability of the findings. The global context of these complex SCNs suggests that the differences between institutional contexts must be explored. For example, the stringency of environmental and social regulation could be taken into account. Similarly, a longitudinal research design could help to explicitly uncover the relationship between sustainability initiatives and financial performance.

It should be also acknowledged that ESG scores may differ between ESG rating agencies, which may affect the results. However, Gregory (2022) concluded in their analysis that the ESG scores of Refinitiv, Bloomberg and S&PGlobal were highly correlated with each other. Moreover, as our sample consists of publicly listed companies, adding tiers to SCNs, in particular SMEs, would provide an insightful future research avenue. As suppliers of large firms, SMEs are typically given the role of the "rule keeper" in terms of sustainability (Stekelorum, 2020). However, these suppliers may play a significant role in increasing visibility and transmitting sustainability requirements. It should also be noted that more than half of the studied firms are from China, USA and Japan, and therefore broadening the geographical coverage would be useful.

As sustainable investing is an increasing trend, the stock markets may allow higher valuations in the future when we start to see more orchestrated networks. Future research may investigate firm- and network-level financial performance outcomes when sustainability at the network level has reached a higher level. Finally, investigating mechanisms that may explain the relationship between structural characteristics and sustainability is necessary. Within the scope of our analysis, we could not determine, for example, what kinds of governance practices buying firms use or how suppliers perceive the pressure from their customers. Integrating the lens of GVC to study governance in global SCNs could set ground in this direction. Future research could uncover how firms of different types perceive their position in the supply network, their possibilities to design or manage the network, and their role in diffusing sustainability.

6. Conclusions

While the importance of SCNs has long been recognized, the scope of empirical studies has rarely entailed large-scale networks. Research on the effect of network structural characteristics on sustainability is still in a nascent stage although these complex and often hidden structures play a major role in sustainable practices. We combined two levels of analysis, the node (firm) and network levels, to investigate structural characteristics and their implications for sustainability and performance. We addressed this objective with a large-scale data-grounded study divided into two parts; the first explores the structural patterns in a network of 5458 companies, and the second takes a deep-dive into a sub-set of 604 companies associated with the automotive industry. Across the largest automotive clusters, we identified four archetypes of sustainability: impassive networks, environmentally focused networks, socially focused networks, and orchestrated networks. Structural characteristics of these networks were found to affect the opportunities of firms and networks to be sustainable.

CRediT author statement

Sini Laari: Conceptualization, Writing- Original draft preparation, Writing - Review & Editing, Formal analysis, Methodology. **Philipp Wetzel:** Conceptualization, Investigation, Data curation, Visualization. **Juuso Töyli:** Conceptualization, Visualization. **Tomi Solakivi:** Conceptualization, Visualization.

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.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank Prof. Dr. Erik Hofmann for his valuable suggestions and comments to this research. Further, the authors also would like to thank the editor and the anonymous reviewers for their constructive and encouraging feedback that greatly helped to improve this article. Sini Laari has received a grant from the Foundation for Economic Education (grant no. 12-6685), which is gratefully acknowledged.

References

Adhikary, A., Sharma, A., Diatha, K.S., Jayaram, J., 2020. Impact of buyer-supplier network complexity on firms' greenhouse gas (GHG) emissions: an empirical investigation. Int. J. Prod. Econ. 230, 107864.
Ahi, P., Searcy, C., 2015. An analysis of metrics used to measure performance in green and sustainable supply chains. J. Clean. Prod. 86, 360–377.
Alinaghian, L., Qiu, J., Razmdoost, K., 2020. The role of network structural properties in supply chain sustainability: a systematic literature review and agenda for future research. Supply Chain Manag.: Int. J. 26 (2), 192–211.
Almeida, C.M.V.B., Bonilla, S.H., Giannetti, B.F., Huisingh, D., 2013. Cleaner Production initiatives and challenges for a sustainable world: an introduction to this special volume. J. Clean. Prod. 47, 1–10.
Awaysheh, A., Klassen, R.D., 2010. The impact of supply chain structure on the use of supplier socially responsible practices. Int. J. Oper. Prod. Manag. 30 (12), 1246–1268.
Bellamy, M.A., Ghosh, S., Hora, M., 2014. The influence of supply network structure on firm innovation. J. Oper. Manag. 32 (6), 357–373.
Behara, R.S., Babbar, S., Smart, P.A., 2014. Leadership in OM research: a social network analysis of European researchers. Int. J. Oper. Prod. Manag. 34 (12), 1537–1563.
Bellamy, M.A., Dhanorkar, S., Subramanian, R., 2020. Administrative environmental innovations, supply network structure, and environmental disclosure. J. Oper. Manag. 66 (7–8), 895–932.
Borgatti, S.P., Li, X., 2009. On social network analysis in a supply chain context. J. Supply Chain Manag. 45 (2), 5–22.
Braziotis, C., Bourlakis, M., Rogers, H., Tannock, J., 2013. Supply chains and supply networks: distinctions and overlaps. Supply Chain Manag.: Int. J. 18 (6), 644–652.
Bundestag, Deutscher, 2021. Entwurf eines Gesetzes über die unternehmerischen Sorgfaltspflichten in Lieferketten. https://dserver.bundestag.de/btd/19/305/1930505.pdf. (Accessed 24 March 2022).
Carnovale, S., Yeniyurt, S., 2015. The role of ego network structure in facilitating ego network innovations. J. Supply Chain Manag. 51 (2), 22–46.
Choi, T.Y., Hong, Y., 2002. Unveiling the structure of supply networks: case studies in Honda, Acura, and DaimlerChrysler. J. Oper. Manag. 20 (5), 469–493.

Choi, T.Y., Kim, Y., 2008. Structural embeddedness and supplier management: a network perspective. J. Supply Chain Manag. 44 (4), 5–13.
Choi, T.Y., Narayanan, S., Novak, D., Olhager, J., Sheu, J.B., Wiengarten, F., 2021. Managing extended supply chains. J. Bus. Logist. 42 (2), 200–206.
Clementino, E., Perkins, R., 2021. How do companies respond to environmental, social and governance (ESG) ratings? Evidence from Italy. J. Bus. Ethics 171, 379–397.
Cole, R., Aitken, J., 2020. The role of intermediaries in establishing a sustainable supply chain. J. Purch. Supply Manag. 26 (2), 100533.
Duque-Grisales, E., Aguilera-Caracuel, J., 2021. Environmental, social and governance (ESG) scores and financial performance of Multilatinas: moderating effects of geographic international diversification and financial slack. J. Bus. Ethics 168, 315–334.
Ekanayake, S., Childerhouse, P., Sun, P., 2017. The symbiotic existence of interorganizational and interpersonal ties in supply chain collaboration. Int. J. Logist. Manag. 28 (3), 723–754.
European Coalition for Corporate Justice, 2022. Comparative Table: Corporate Due Diligence Laws and Legislative Proposals in Europe. https://corporatejustice.org/publications/comparative-table-corporate-due-diligence-laws-and-legislative-proposals-in-europe-2/. (Accessed 12 July 2022).
European Parliament Proposal for a Directive on Corporate Sustainability due Diligence and Annex, 2022. https://ec.europa.eu/info/publications/proposal-directive-corporate-sustainable-due-diligence-and-annex_en. (Accessed 20 April 2022).
Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E.A., Barlow, C.Y., 2017. Business model innovation for sustainability: towards a unified perspective for creation of sustainable business models. Bus. Strat. Environ. 26 (5), 597–608.
Ferns, G., Amaeshi, K., Lambert, A., 2019. Drilling their own graves: how the European oil and gas supermajors avoid sustainability tensions through mythmaking. J. Bus. Ethics 158 (1), 201–231.
Gereffi, G., Lee, J., 2016. Economic and social upgrading in global value chains and industrial clusters: why governance matters. J. Bus. Ethics 133, 25–38.
Girvan, M., Newman, M.E., 2002. Community structure in social and biological networks. Proc. Natl. Acad. Sci. 99 (12), 7821–7826.
Gong, Y., Jia, F., Brown, S., Koh, L., 2018. Supply chain learning of sustainability in multi-tier supply chains: a resource orchestration perspective. Int. J. Oper. Prod. Manag. 38 (4), 1061–1090.
Govindan, K., Shaw, M., Majumdar, A., 2021. Social sustainability tensions in multi-tier supply chain: a systematic literature review towards conceptual framework development. J. Clean. Prod. 279, 123–175.
Granovetter, M., 1985. Economic action and social structure: the problem of embeddedness. Am. J. Sociol. 91 (3), 481–510.
Gregory, R.P., 2022. The influence of firm size on ESG score controlling for ratings agency and industrial sector. J. Sustain. Finance Invest. 1–14.
Gualandris, J., Longoni, A., Luzzini, D., Pagell, M., 2021. The association between supply chain structure and transparency: a large-scale empirical study. J. Oper. Manag. 67 (7), 803–827.
Guardian, 2021. Court orders Royal Dutch Shell to cut carbon emissions by 45% by 2030. https://www.theguardian.com/business/2021/may/26/court-orders-royal-dutch-shell-to-cut-carbon-emissions-by-45-by-2030. accessed 14.9.2022.
Gyönyörová, L., Stachoň, M., Stašek, D., 2021. ESG ratings: relevant information or misleading clue? Evidence from the S&P Global 1200. J. Sustain. Finance & Invest. 1–35.
Hadi, S., Baskaran, S., 2021. Examining sustainable business performance determinants in Malaysia upstream petroleum industry. J. Clean. Prod. 294, 126–231.
Han, Y., Caldwell, N.D., Ghadge, A., 2020. Social network analysis in operations and supply chain management: a review and revised research agenda. Int. J. Oper. Prod. Manag. 40 (7/8), 1153–1176.
Hartmann, J., 2021. Toward a more complete theory of sustainable supply chain management: the role of media attention. Supply Chain Manag.: Int. J. 26 (4), 532–547.
Hartmann, J., Moeller, S., 2014. Chain liability in multitier supply chains? Responsibility attributions for unsustainable supplier behavior. J. Oper. Manag. 32 (5), 281–294.
Hartmann, J., Inkpen, A., Ramaswamy, K., 2021. The oil and gas industry: finding the right stance in the energy transition sweepstakes. J. Bus. Strat. 43 (1), 17–27.
Hofmann, H., Schleper, M.C., Blome, C., 2018. Conflict minerals and supply chain due diligence: an exploratory study of multi-tier supply chains. J. Bus. Ethics 147, 115–141.
Hwang, W., Kim, T., Ramanathan, M., Zhang, A., 2008, August. Bridging centrality: graph mining from element level to group level. In: Proceedings of the 14th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, pp. 336–344.
Hyder, A.S., Chowdhury, E., Sundström, A., 2017. Balancing control and trust to manage CSR compliance in supply chains. Int. J. Supply Chain Manag. 6 (2), 1–14.
Johnsen, T.E., Mikkelsen, O.S., Wong, C.Y., 2019. Strategies for complex supply networks: findings from the offshore wind power industry. Supply Chain Manag: An. Int. J. 24 (6), 872–886.
Kauppi, K., Hannibal, C., 2017. Institutional pressures and sustainability assessment in supply chains. Supply Chain Manag.: Int. J. 22 (5), 458–547.
Kim, Y., Choi, T.Y., Yan, T., Dooley, K., 2011. Structural investigation of supply networks: a social network analysis approach. J. Oper. Manag. 29 (3), 194–211.
Koberg, E., Longoni, A., 2019. A systematic review of sustainable supply chain management in global supply chains. J. Clean. Prod. 207, 1084–1098.
Krause, D.R., Vachon, S., Klassen, R.D., 2009. Special topic forum on sustainable supply chain management: introduction and reflections on the role of purchasing management. J. Supply Chain Manag. 45 (4), 18–25.
Kusi-Sarpong, S., Mubarik, M.S., Khan, S.A., Brown, S., Mubarak, M.F., 2022. Intellectual capital, blockchain-driven supply chain and sustainable production: role of supply chain mapping. Technol. Forecast. Soc. Change 175, 121331.
Lanier Jr., D., Wempe, W.F., Zacharia, Z.G., 2010. Concentrated supply chain membership and financial performance: chain-and firm-level perspectives. J. Oper. Manag. 28 (1), 1–16.
Leppelt, T., Foerstl, K., Hartmann, E., 2013. Corporate social responsibility in buyer-supplier relationships: is it beneficial for top-tier suppliers to market their capability to ensure a responsible supply chain? Bus. Res. 6 (2), 126–152.
Li, Y., Zobel, C.W., 2020. Exploring supply chain network resilience in the presence of the ripple effect. Int. J. Prod. Econ. 228, 107–693.
Lourenço, I.C., Branco, M.C., Curto, J.D., Eugénio, T., 2012. How does the market value corporate sustainability performance? J. Bus. Ethics 108 (4), 417–428.
Marques, L., 2019. Sustainable supply network management: a systematic literature review from a knowledge perspective. Int. J. Prod. Perform. Manag. 68 (6), 1164–1190.
Marshall, D., McCarthy, L., Heavey, C., McGrath, P., 2015. Environmental and social supply chain management sustainability practices: construct development and measurement. Prod. Plann. Control 26 (8), 673–690.
Mathivathanan, D., Kannan, D., Haq, A.N., 2018. Sustainable supply chain management practices in Indian automotive industry: a multi-stakeholder view. Resour. Conserv. Recycl. 128, 284–305.
Meehan, J., Pinnington, B.D., 2021. Modern slavery in supply chains: insights through strategic ambiguity. Int. J. Oper. Prod. Manag. 41 (2), 77–101.
Meinlschmidt, J., Schleper, M.C., Foerstl, K., 2018. Tackling the sustainability iceberg: a transaction cost economics approach to lower tier sustainability management. Int. J. Oper. Prod. Manag. 38 (10), 1888–1914.
Mena, C., Humphries, A., Choi, T.Y., 2013. Toward a theory of multi-tier supply chain management. J. Supply Chain Manag. 49 (2), 58–77.
Meqdadi, O.A., Johnsen, T.E., Johnsen, R.E., 2019. Power and diffusion of sustainability in supply networks: findings from four in-depth case studies. J. Bus. Ethics 159 (4), 1089–1110.
Montabon, F., Pagell, M., Wu, Z., 2016. Making sustainability sustainable. J. Supply Chain Manag. 52 (2), 11–27.
Murcia, M.J., Panwar, R., Tarzijan, J., 2021. Socially responsible firms outsource less. Bus. Soc. 60 (6), 1507–1545.
Paolucci, E., Pessot, E., Ricci, R., 2021. The interplay between digital transformation and governance mechanisms in supply chains: evidence from the Italian automotive industry. Int. J. Oper. Prod. Manag. 41 (7), 1119–1144.
Pathak, S.D., Wu, Z., Johnston, D., 2014. Toward a structural view of co-opetition in supply networks. J. Oper. Manag. 32 (5), 254–267.
Pedersen, E.R.G., Gwozdz, W., Hvass, K.K., 2018. Exploring the relationship between business model innovation, corporate sustainability, and organisational values within the fashion industry. J. Bus. Ethics 149, 267–284.
Provan, K.G., Fish, A., Sydow, J., 2007. Interorganizational networks at the network level: a review of the empirical literature on whole networks. J. Manag. 33 (3), 479–516.
Quarshie, A.M., Salmi, A., Leuschner, R., 2016. Sustainability and corporate social responsibility in supply chains: the state of research in supply chain management and business ethics journals. J. Purch. Supply Manag. 22 (2), 82–97.
Refinitiv, 2022. Environmental, Social and Governance Scores from Refinitiv. Available at: https://www.refinitiv.com/content/dam/marketing/en_us/documents/methodology/refinitiv-esg-scores-methodology.pdf. (Accessed 12 July 2022).
Rhodes, C., 2016. Democratic business ethics: Volkswagen's emissions scandal and the disruption of corporate sovereignty. Organ. Stud. 37 (10), 1501–1518.
Sauer, P.C., Seuring, S., 2017. Sustainable supply chain management for minerals. J. Clean. Prod. 151, 235–249.
Saunders, L.W., Tate, W.L., Zsidisin, G.A., Miemczyk, J., 2019. The influence of network exchange brokers on sustainable initiatives in organizational networks. J. Bus. Ethics 154 (3), 849–868.
Schilling, M.A., Phelps, C.C., 2007. Interfirm collaboration networks: The impact of large-scale network structure on firm innovation. Manag. Sci. 53 (7), 1113–1126.
Schmidt, C.G., Foerstl, K., Schaltenbrand, B., 2017. The supply chain position paradox: green practices and firm performance. J. Supply Chain Manag. 53 (1), 3–25.
Schöggl, J.P., Fritz, M.M., Baumgartner, R.J., 2016. Toward supply chain-wide sustainability assessment: a conceptual framework and an aggregation method to assess supply chain performance. J. Clean. Prod. 131, 822–835.
Schuerch, R., Biggoer, S., 2021. Neue menschenrechtliche Pflichten für Schweizer Unternehmen trotz Ablehnung der Konzernverantwortungsinitiative. J. Hum. Rights/Z. Menschenrechte 15 (1).
Seiler, A., Papanagnou, C., Scarf, P., 2020. On the relationship between financial performance and position of businesses in supply chain networks. Int. J. Prod. Econ. 227, 107690.
Siems, E., Land, A., Seuring, S., 2021. Dynamic capabilities in sustainable supply chain management: an inter-temporal comparison of the food and automotive industries. Int. J. Prod. Econ. 236, 108128.
Sinkovics, N., Sinkovics, R.R., Archie-Acheampong, J., 2021. Small-and medium-sized enterprises and sustainable development: in the shadows of large lead firms in global value chains. J. Int. Bus. Pol. 4 (1), 80–101.
Sodhi, M.S., Tang, C.S., 2019. Research opportunities in supply chain transparency. Prod. Oper. Manag. 28 (12), 2946–2959.
Soytas, M.A., Denizel, M., Usar, D.D., 2019. Addressing endogeneity in the causal relationship between sustainability and financial performance. Int. J. Prod. Econ. 210, 56–71.
Stekelorum, R., 2020. The roles of SMEs in implementing CSR in supply chains: a systematic literature review. Int. J. Logist. Res. Appl. 23 (3), 228–253.

Stoltenberg, D., Maier, D., Waldherr, A., 2019. Community detection in civil society online networks: theoretical guide and empirical assessment. Soc. Network. 59, 120–133.
Su, H.C., Kao, T.W.D., Linderman, K., 2020. Where in the supply chain network does ISO 9001 improve firm productivity? Eur. J. Oper. Res. 283 (2), 530–540.
Tachizawa, E.M., Wong, C.Y., 2014. Towards a theory of multi-tier sustainable supply chains: a systematic literature review. Supply Chain Manag.: Int. J. 19 (5/6), 643–663.
Tajbakhsh, A., Hassini, E., 2015. Performance measurement of sustainable supply chains: a review and research questions. Int. J. Prod. Perform. Manag. 64 (6), 744–783.
Tate, W.L., Ellram, L.M., Gölgeci, I., 2013. Diffusion of environmental business practices: a network approach. J. Purch. Supply Manag. 19 (4), 264–275.
Trujillo-Gallego, M., Sarache, W., Sellitto, M.A., 2021. Identification of practices that facilitate manufacturing companies' environmental collaboration and their influence on sustainable production. Sustain. Prod. Consum. 27, 1372–1391.
Uzzi, B., 1997. Social structure and competition in interfirm networks: the paradox of embeddedness. Adm. Sci. Q. 35–67.
Van Hoof, B., 2014. Organizational learning in cleaner production among Mexican supply networks. J. Clean. Prod. 64, 115–124.
Vandchali, H.R., Cahoon, S., Chen, S.L., 2021. The impact of supply chain network structure on relationship management strategies: an empirical investigation of sustainability practices in retailers. Sustain. Prod. Consum. 28, 281–299.
Vieira, L.C., Amaral, F.G., 2016. Barriers and strategies applying Cleaner Production: a systematic review. J. Clean. Prod. 113, 5–16.
Villena, V.H., Gioia, D.A., 2018. On the riskiness of lower-tier suppliers: Managing sustainability in supply networks. J. Oper. Manag. 64, 65–87.
Villena, V.H., Wilhelm, M., Xiao, C.Y., 2021. Untangling drivers for supplier environmental and social responsibility: an investigation in Philips Lighting's Chinese supply chain. J. Oper. Manag. 67 (4), 476–510.
Vurro, C., Russo, A., Perrini, F., 2009. Shaping sustainable value chains: network determinants of supply chain governance models. J. Bus. Ethics 90 (4), 607–621.
Wahl, A., Bull, G.Q., 2014. Mapping research topics and theories in private regulation for sustainability in global value chains. J. Bus. Ethics 124 (4), 585–608.
Wall Street Journal, 2021. Climate ruling could force big change at Shell. https://www.wsj.com/articles/climate-ruling-could-force-big-change-at-shell-11622131737. accessed 14.9.2022.
Wan Ahmad, W.N.K., de Brito, M.P., Tavasszy, L.A., 2016. Sustainable supply chain management in the oil and gas industry: a review of corporate sustainability reporting practices. Benchmark Int. J. 23 (6), 1423–1444.
Wetzel, P., Hofmann, E., 2019. Supply chain finance, financial constraints and corporate performance: an explorative network analysis and future research agenda. Int. J. Prod. Econ. 216, 364–383.
Wichmann, B.K., Kaufmann, L., 2016. Social network analysis in supply chain management research. Int. J. Phys. Distrib. Logist. Manag. 46 (8), 740–762.
Wiedmer, R., Griffis, S.E., 2021. Structural characteristics of complex supply chain networks. J. Bus. Logist. 42 (2), 264–290.
Wiedmer, R., Rogers, Z.S., Polyviou, M., Mena, C., Chae, S., 2021. The dark and bright sides of complexity: a dual perspective on supply network resilience. J. Bus. Logist. 42 (3), 336–359.
Wilhelm, M., Villena, V.H., 2021. Cascading sustainability in multi-tier supply chains: when do Chinese suppliers adopt sustainable procurement? Prod. Oper. Manag. 30 (11), 4198–4218.
Wilhelm, M.M., Blome, C., Bhakoo, V., Paulraj, A., 2016a. Sustainability in multi-tier supply chains: understanding the double agency role of the first-tier supplier. J. Oper. Manag. 41, 42–60.
Wilhelm, M., Blome, C., Wieck, E., Xiao, C.Y., 2016b. Implementing sustainability in multi-tier supply chains: strategies and contingencies in managing sub-suppliers. Int. J. Prod. Econ. 182, 196–212.
Wu, G.C., 2017. Effects of socially responsible supplier development and sustainability-oriented innovation on sustainable development: empirical evidence from SMEs. Corp. Soc. Responsib. Environ. Manag. 24 (6), 661–675.
Xu, M., Cui, Y., Hu, M., Xu, X., Zhang, Z., Liang, S., Qu, S., 2019. Supply chain sustainability risk and assessment. J. Clean. Prod. 225, 857–867.
Yang, Y.S., Choi, T.Y., Carter, C.R., Yin, R., 2022. Expanding the boundaries of buyer-supplier agency problems: moving from dyad to triad. J. Purch. Supply Manag., 100749
Zhou, Y.M., Wan, X., 2017. Product variety and vertical integration. Strat. Manag. J. 38 (5), 1134–1150.