

CRANFIELD UNIVERSITY

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THE INFLUENCE OF SUPPLY NETWORK STRUCTURE ON FIRM
SUSTAINABILITY

SCHOOL OF MANAGEMENT
Management and Leadership

PhD
Academic Year: 2017 - 2023

Supervisor: Dr Leila Alinaghian
Dr Kamran Razmdoost

March 2023

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Supervisor: Dr Leila Alinaghian
Dr Kamran Razdmoost

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the degree of PhD

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ABSTRACT

Firms are facing increased pressure from various stakeholders to incorporate social and environmental considerations into their strategies and operations. Yet, the successful realisation and achievement of social and environmental objectives extend beyond the boundaries of one single firm. Firms more and more engage in relationships with various upstream and downstream actors across their supply chains to achieve these sustainability goals. Whilst the literature has highlighted the cruciality of the broader supply networks in driving firms' sustainability, present literatures as a whole lacks both a synthesis of major findings and a reflection of the current development of this area. Adopting a Systematic Literature Review approach, the thesis extends the understanding of the role of network in supply chain sustainability by identifying distinct network attributes that influence the sustainability performance in the supply chain. Specifically, relational and structural network attributes are distinguished and their individual and interactive effects on both environmental and social dimensions of sustainability in supply chains are examined. The study further adds contributions to the current discussion on the cruciality of broader supply networks in driving sustainability by investigating the interfirm connectivity patterns of a real-world and large-scale Automotive supply network. The findings demonstrate a positive relationship between the interconnectedness of supply networks and firms' sustainability performance. The study also determines the moderating role of firms' supply network structural properties in the relationship between their sustainability efforts and sustainability performance; the study shows that whereas firms' in-degree centrality weakens the relationship between their commitment to sustainability and the extent of sustainability performance, out-degree centrality strengthens this association. The thesis further adds to the existing literature examining the role of supply network structural properties by investigating the structural properties of firms' neighbours. Particularly, the study distinguishes between two neighbours' structural properties: neighbours' interconnectedness and neighbours' centrality. Moreover, the study determines the moderating effect of firms' bridging in sustainability controversies. In addition to the sustainability outcome, the study examines firms' sustainability

controversies as an alternative indicator of sustainability performance capturing the importance and significance of the sustainability outcomes through market sensitivities (i.e. market reactions to sustainability conflicts).

Keywords:

Supply chain sustainability, Sustainable supply chain management, Sustainability performance, Sustainability controversies, Supply networks, Social network analysis

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LIST OF ABBREVIATIONS

SLR	Systematic Literature Review
OLS	Ordinary Least Square
SSCM	Sustainable Supply Chain Management
SNA	Social Network Analysis
ESG	Environmental, Social and Governance
NGO	Non-government Organisation
CSR	Corporate Social Responsibility
VIF	Variance Inflation Factor
DID	Difference-in-Difference

1 Introduction

1.1 Research rationale

Supply chain sustainability refers to companies across supply chains that manage the environmental, social, and economic impacts of products and services during their life cycles involving the cooperation among companies (Seuring & Müller, 2008). Due to the large and increasing number of actors involved - i.e. design, production, and delivery – with the products and services, sustainability extends outside the boundaries of one firm (Alinaghian et al., 2021). As a result, firms increasingly focus and invest in forming and maintaining relationships with external upstream and downstream actors to manage the impacts of sustainability (Chen et al., 2017; Sudusinghe & Seuring, 2022). For the last two decades, researchers have studied in depth the role of supply chain collaboration, in general, but particularly supply chain relationships' qualities: trust, information sharing, and power in driving supply chain sustainability (e.g. Ahmed & Shafiq, 2022; Cheng et al., 2008; Khan et al., 2016). However, the focus of the literature has been predominantly on the dyadic perspective that has examined the relationship between firms and their first-tier suppliers.

Scholars have more recently begun to address the broader direct and indirect network of relationships in which firms are embedded in the supply network. Particularly, various strands of literature have emerged regarding driving supply chain sustainability across this broader network of relationships. For instance, multi-tier Sustainable Supply Chain Management (SSCM) literature assessed how multiple tier supply chain members unite to tackle supply chain sustainability issues to reach their sustainability goals (e.g. Sauer & Seuring, 2019; Tachizawa & Wong, 2014). Additionally, embryonic work has theorised and researched the role connectivity patterns (i.e. supply network structures) of supply chain firms in their sustainability behaviour and performance (e.g. Saunders et al., 2019; Tate et al., 2013). In essence, this literature examined and studied different supply network structural properties that prove highly important in the embedded firms' sustainability outcomes. Whilst the literature has demonstrated the importance of the broader supply networks in driving firms' sustainability, as a whole, there

appears to be little synthesis of major findings and an expression of the current developments in this area. More precisely, there is a need for a more structured theoretical representation of how the various network properties linking firms in the supply chain can underpin embedded firms' and network's sustainability performance.

Moreover, even though scholars have started to debate the role of supply network structural properties in relation to sustainability performance of the embedded firms, there is a lack of empirical grounding in the literature. The structural properties emerging in supply networks have been extensively observed (Brintrup & Ledwoch, 2018). Large-scale supply networks' data have been used in recent years where scholars have looked at the effect of supply network structural properties on innovation (e.g. Bellamy et al., 2014; Sharma et al., 2020) or resilience (e.g. Basole & Bellamy, 2014) of the embedded firms. However, an empirical investigation of wide-ranging, actual supply networks to examine how the structural properties of supply networks, in which *firms* and their surrounding *neighbours* (i.e. a firm's network of direct connections) are embedded, drive sustainability performance has yet to be attempted.

Additionally, the extant studies examining firms' sustainability performance have largely focused on firms' practices. For instance, prior studies have adopted different proxies such as sustainability transparency and disclosure (Bellamy et al., 2020; Gualandris et al., 2021) or sustainability outcomes (Ozcan, 2011; De Burgos Jiménez & Céspedes, 2001; Dremptetic et al., 2020) when evaluating the sustainability performance of firms. Yet, these studies fall short when evaluating the market reactions to sustainability conflicts, i.e. the conflicts that organisations face with stakeholders when their behaviour along the supply chain, such as modern slavery or environmental scandals, damages their environmental or social sustainability (Dasgupta et al., 2006; Tamayo-Torres et al., 2019). Firms' sustainability controversies are a stronger indicator of sustainability performance as they capture both the importance and significance of the sustainability issues through the market sensitivities (Tamayo-Torres et al., 2019).

1.2 Research aim and objectives

This thesis' aim is to investigate the relationship between the structural properties of supply networks in which firms are embedded and their sustainability performance. Hence, the principal research question is:

How do the structural properties of supply networks affect firms' sustainability performance?

To address the research question, I conducted three studies. These are presented in Chapter 2, Chapter 3, and Chapter 4 in the form of three papers (i.e. Paper 1, Paper 2, and Paper 3) with three objectives as below:

- Objective 1 (Paper 1): Undertake a systematic review and assessment of current research on supply chain sustainability from a network perspective and provide an organisational lens for future scholarship in this field.
- Objective 2 (Paper 2): Empirically examine the influence of the structural properties of firms' supply networks with regard to their sustainability performance.
- Objective 3 (Paper 3): Empirically examine the influence of the structural properties of supply networks in which firms' neighbours are embedded on firms' sustainability controversies.

1.3 Mapping the field

The main areas of literature for this research were determined as: supply chain sustainability and supply chain network analysis, focussing on the overlap of these two domains. By exploring the related literature, the research would focus on the intersection of the two (Figure 1-1). The relevant intersection analysis will be provided in the next section.

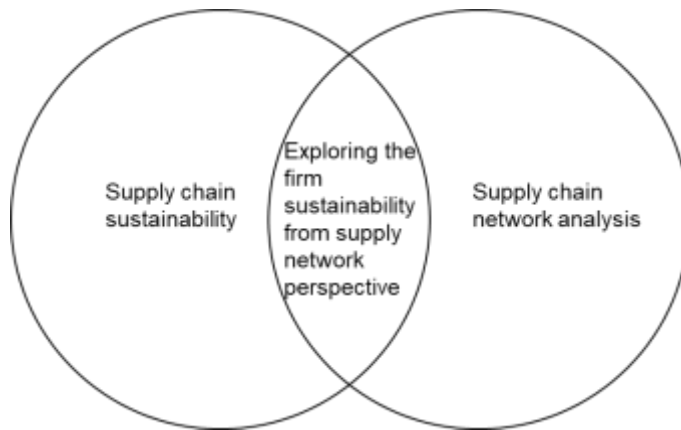


Figure 1-1 Map of literature domains

1.3.1 Supply chain sustainability

There has been a rapid increase in this research field to incorporate sustainability into the management of supply chains, which has been studied extensively in the existing studies (e.g. Arora & Brintrup, 2021; Tsolakis et al., 2021; Yang et al., 2018) through the concept of SSCM (Alinaghian et al., 2021). In investigating SSCM, prior scholars have devoted significant attention to internal and external practices adopted by firms to attain sustainability (Gimenez et al., 2012). First, researchers explored SSCM and the behavioural aspects by investigating firms' values, attitudes, and orientation towards sustainability. For instance, prior studies have suggested adopting sustainability initiatives (Dou et al., 2018) or including initiatives as a part of the firm's mission (Pagell & Wu, 2009). Second, prior studies also advised that firms introduce different processes, e.g. setting up sustainability codes of conduct or environmental and social conditions to disseminate through sustainability targets across the supply chain (Tachizawa & Wong, 2014). Moreover, firms could even engage in a collaborative process to develop a set of sustainability capabilities (e.g. Arora & Brintrup, 2021) and introduce sustainable innovations (Beske et al., 2014). In addition, firms could perhaps use a monitoring process, e.g. audits that examine the sustainability performance of network members (Tachizawa & Wong, 2014).

Yet, existing literature primarily examined firms' SSCM practices in relation to the direct connections (e.g. first-tier supply chain members). Recent studies have begun to shift their focus to the role of broader network relationships and how

they achieve sustainability goals (e.g. Sauer & Seuring, 2019; Touboullic et al., 2018). In particular, two threads of literature concentrated on the structure of supply network and its effect on supply chain sustainability. The first thread adopted the social network analysis (SNA) approach, highlighting the cruciality of connectivity patterns surrounding supply chain members (i.e. the supply network structure). For example, these studies examined different network structural properties, e.g. centrality and density that may have an impact on the sustainability performance of the embedded firms (e.g. Laari et al., 2022; Tate et al., 2013). Another area of the SSCM literature pinpointed the management, orchestration, and governance of multi-tier supply chains (e.g. Sauer & Seuring, 2018). Although this area of literature did not acknowledge these explicit structural properties, the interconnected findings relative to multi-tier supply chain members can be useful in providing insights on network structural properties. As an example, a focal firm, sidestepping its first-tier suppliers, could establish a direct approach with its lower-tier suppliers in terms of sustainability, which could lead to a highly-centralised network position for the focal firm. Thus, the governance mechanisms adopted by a focal firm to manage the lower-tier suppliers may aid the generation of pertinent connectivity patterns within supply networks (e.g. Villena & Gioia, 2020).

1.3.2 Supply chain network analysis

Previous supply chain management studies have primarily emphasised on the dyadic lens, i.e. buyer-seller, manufacturer-seller, retailer-supplier, etc. in supply chain collaboration (e.g. Chen et al., 2017). However, as the supply chain is known as a network consisting of a set of nodes along with associated ties, dyads do not capture the crux of a network (Choi & Wu, 2009). Interest in triads and more than triadic relationships in supply network is, therefore, growing (e.g. Choi & Wu, 2009; Wynstra & Wetzels, 2010; Zou & Wang, 2022), and social network analysis (SNA) is an analytical method to examine numerous network connectivity patterns to glean inferences on the entire supply network.

In examining the SNA literature, it provides a lens considering the network that consists of a focal firm, the set of firms with any kind of tie to the focal firm, and

all ties amongst firms (Borgatti & Li, 2009). Moreover, ties are conceptualised as structures of physical flows of materials or contractual relationships between firms. In addition, previous studies (Alinaghian et al., 2021) also theorised a new form of tie to communicate, monitor and/or collaborate with other firms regarding sustainability (i.e. sustainability tie).

Recently, there has been a rapid increase in the adoption of SNA in visualising and assessing connectivity patterns in supply chains (e.g. Bellamy et al., 2014; Han et al., 2020; Lu et al., 2018). Specifically, two levels of analysis have been mainly examined, i.e. node/firm-level and whole-network-level. Node/firm-level properties examine how individual firms are embedded in a network from its own lens. For instance, the degree centrality, closeness centrality, and betweenness centrality are one of the most fundamental node-level properties and have been examined by prior studies (Borgatti & Li, 2009). On the contrary, the whole-network-level properties assessed how the overall network connections are arranged overall (Kim et al., 2011). For instance, prior studies adopted several network-level properties, such as network density, network diversity, etc. Building upon that, recent scholars examined the diversified issues in the supply network with SNA, for example, supply chain disruption and resilience (Kim et al., 2015), firm innovation (Bellamy et al., 2014), and risk diffusion (Basole & Bellamy, 2014). The extension of SNA to supply chain management renders scholars a better comprehension of the operations of the supply network from a network viewpoint. However, there is still a lack of studies that address the sustainability of the supply chains through the network lens.

In light of these discussions, insights into the gaps left by those prior studies are apparent, which opens up areas for this thesis. In this thesis, I therefore embrace SNA, as a theoretical lens and an analytical approach, to investigate the influence of supply network structure on firms' sustainability (i.e. the juncture of supply chain network analysis and supply chain sustainability).

1.4 Theoretical underpinning

In examining the impact of supply network structural properties on a firm's sustainability performance, this thesis mainly applied the social network theory throughout Chapter 2 to Chapter 4.

From a social network analysis perspective, a network consists of nodes representing the network members and the linkages or ties that connect those (Borgatti & Li, 2009). With regard to the supply network, nodes consist of suppliers, manufacturers, service providers, and consumers that are linked together through delivery and receipt of materials, components, and modules or via a supply contract (Bellamy et al., 2014; Choi & Hong, 2002; Kim et al., 2011). Previous studies have also largely conceptualised ties in the form of physical flows (e.g. materials) or contractual relationships (Choi & Hong, 2002). In line with this, recent scholars have begun to adopt network metrics to symbolise network structural properties in the supply network and observe their influence on behaviour and performance (e.g. Kim et al., 2011; Han et al., 2020). For instance, the role of different supply network structural properties of embedded firms regarding innovation (e.g. Bellamy et al., 2014) or effectiveness of risk management and resilience (e.g. Kim et al., 2015; Ledwoch et al., 2018). Aligned with these studies and to address the sustainability performance, this theory will be further explained in the relevant sections of papers in this thesis.

1.5 Research methodology

The research methodology and analysis tools adopted in Papers 1–3 are presented in the following sections.

1.5.1 Systematic literature review

Paper 1, as presented in Chapter 2, adopted a systematic literature review (SLR) approach (Tranfield et al., 2003). The paper followed three stages, namely: locating the studies, selection and evaluation of the studies, and extraction and synthesis of the data. The literature search was executed across three databases, i.e. Scopus, EBSCO, and ABI/INFORM, by applying several groupings of relevant keywords (i.e. search strings). Following a rigorous filtration

process, 52 studies across 17 peer-reviewed journals from 2003 to 2018 were selected for final review. The detailed process of search and selection of studies is detailed in Chapter 2.

1.5.2 Empirical work

The first empirical paper (Paper 2) investigated the impact of supply network structure on a firm's sustainability performance, whilst the second empirical paper (Paper 3) shifted the focus to the neighbours' networks and their influence on firms' sustainability controversies. Thus, different hypotheses in Papers 2 and 3 have been developed.

Empirical setting

Drawing upon the propositions in paper 1, the first empirical paper investigated the effect of supply network structure on a firm's sustainability performance. The automotive industry is considered as an appropriate setting for the following reasons. First, due to gradual dis-verticalisation within the industry, firms have had to depend on a highly disjointed network of partners in providing products and services. In the meantime, the industry environment has increasingly burdened firms to continually minimise the adverse effects on the environment and society. This extreme fragmented setting, where firms' comprehension and achievement of sustainability goals rely on networks of relationships in which they are embedded, provides a fitting empirical research scenario to explore the role of supply network connectivity patterns in a firm's sustainability operations.

The data and samples

I used the supply network data that were retrieved from MarkLines Automotive Information platform in 2014. The data consisted of customers and suppliers of firms that advertise themselves on the database as well as the connections between firms. Overall, the supply network consisted of 18,943 firms and 103,632 links between them. Gephi, open-source software, was used to visualise and calculate firm-level network structural metrics. The sustainability data were retrieved from Thomson Reuters Environmental, Social and Governance (ESG) database. In Paper 2, I used ESG scores as an indicator of firm's sustainability

performance. I collected scores on environmental (i.e. emission, resource use, environmental innovation) and social indicators (i.e. workforce, human rights, community and product responsibility). I used time lagged scores to better reflect the causal impact of the proposed determinants (Rajesh, 2020). In Paper 3, I used Thomson Reuters Eikon controversy scores as an indicator of firms' sustainability controversies. I checked the availability of sustainability performance data for the entire network of 18,943 firms, where ultimately a sample of 273 firms for Paper 2 and 268 firms for Paper 3 were identified. The financial-related data and non-financial-related data for the control variables were obtained from the Bloomberg SPLC database and Thomson Eikon database as previous scholars had suggested a similar approach (Kim & Zhu, 2018).

The analysis

In line with the previous empirical investigations, a multicollinearity check was applied and the variance inflation factor (VIF) mean scores for the datasets in Papers 2 and 3 are below 2, indicating there are no multicollinearity issues (Neter et al., 1996). Furthermore, the Ordinary Least Square (OLS) regression method was adopted, which is considered more accurate and stable. After that, a robustness check was undertaken to ensure model stability and verify any significant effect is robust considering all other effects. I adopted the similar approach recommended by Gentry and Shen (2013) and replaced variables with different ways (i.e. missing values with an average adopted an alternative measure of variables in different years) and it shows no significant changes to the original results. These processes have been detailed in Chapter 3 and Chapter 4.

1.6 Summary of contributions

This thesis adds to the existing SSCM literature, particularly the literature that examines supply network structural properties in various ways. First, in accordance with the first objective, Paper 1 (Chapter 2) employs an SLR approach to examine and synthesise the main scholarly discussions on supply chain sustainability from a network perspective. The study expands the understanding of the role of network in supply chain sustainability by identifying

distinct network attributes that impact on supply chain sustainability performance. Specifically, relational and structural network attributes are distinguished and the individual and interactive effects on the environmental and social dimensions of sustainability in supply chains are examined.

Second, Paper 2 (Chapter 3) contributes to the current discussion on the criticality of broader supply networks in driving sustainability by investigating the interfirm connectivity patterns of a real-world and large-scale Automotive supply network. The study demonstrates a positive association between the interconnectedness of supply networks and firms' sustainability performance. The study also determines the moderating role of a firm's supply network structural properties through the link between their sustainability efforts and performance. By distinguishing between firms' upstream and downstream ties, the study shows that whereas firms' in-degree centrality weakens the rapport between their commitment to sustainability and the extent of sustainability performance, out-degree centrality strengthens this association.

Furthermore, Paper 3 (Chapter 4) contributes to the existing literature examining the role of supply network structural properties by investigating the structural properties of firms' neighbours. Particularly, this study distinguished between two network structural properties that consider the perspective of its neighbouring firms. Moreover, the study determines the moderating effect of firms' bridging in sustainability controversies. Although previous studies have emphasised the important role of firm's bridging position in sustainability, they have not interrogated the interplay of firms' bridging position and neighbour's network structural properties in shaping sustainability controversies.

Lastly, in examining the role of supply network structural properties in firms' sustainability, in addition to sustainability performance, this thesis examines sustainability controversies as an alternative indicator, which captures both the focal firm's sustainability practices as well as external market reactions.

1.7 Publications, conference presentations, and future plans

As mentioned, this thesis is formed by three independent papers. The thesis format was chosen because the dissemination of the research outcomes could be obtained from the conclusion of each paper. Table 1-1 summarises each paper's publication and presentation details throughout the PhD journey together with future plans, where applicable. Additionally, the feedback received as a result of these publications and presentations was extremely helpful as it aided the author to further develop each paper and improve the thesis cohesion.

Table 1-1 Summary of publications, presentations and future plans

Paper	Title	Journal Submission	Conference Submission
1	The role of networks in supply chain sustainability performance: a systematic review and agenda for future research	•Submitted to Supply Chain Management: an International Journal (SCM: IJ). •An adapted version is now published in the SCM: IJ	•Early abbreviated version accepted and presented at EurOMA 2019. •Early abbreviated version (as a developmental paper) accepted and presented at the British Academy of Management (BAM) 2019.
2	The role of supply network structural properties on firm sustainability: an empirical investigation	•Submitted to the Journal of Supply Chain Management (R&R)	•Early version accepted and presented (virtually) at the Academy of Management (AOM) conference in 2021. Published in the AOM

			conference proceedings. •Early abbreviated version accepted and presented (virtually) at EurOMA 2021.
3	The role of neighbours' supply network structure in firm's sustainability controversies		Early abbreviated version accepted at EurOMA 2023.

1.8 Thesis structure

The thesis is organised as follows (the thesis' structure flowchart is shown in Figure 1-2): Chapters 2 to 4 are devoted to papers 1 to 3, which formed the basis of the thesis' research aim and objectives. Chapter 2 presents the Systematic Literature Review and the review paper was submitted to and presented at both the 2019 European Operations Management Association (EurOMA) and British Academy of Management (BAM) conferences. Building on the feedback from the conferences, this review paper was then also submitted to Supply Chain Management: An International Journal (SCM: IJ). After contemplating reviewers' comments, the authors decided to develop a different version of paper and adapted it as "The role of network structural properties in supply chain sustainability: a systematic literature review and agenda for future research" and it was successfully published in SCM: IJ journal. Chapter 2 provides the basis for the next two chapters. Thus, Chapter 3 and Chapter 4's empirical papers were developed based on the relevant theoretical results from the systematic literature review.

Chapter 3 delivers the first empirical paper, which is one of the first empirical papers in existing literature investigating the influence of supply network structure

on sustainability performance from an empirical grounding. An earlier, abbreviated form of this empirical paper was submitted to and presented at the 2021 Academy of Management (AOM) and EurOMA conferences. Furthermore, the paper was also put forward for consideration by the Journal of Supply Chain Management and received a R&R result.

Chapter 4 illustrates the second empirical paper in this thesis. In this paper, a different aspect of sustainability and network concepts are considered. This paper was submitted to and will be presented at the 2023 EurOMA conference.

Building on the contributions of the systematic literature review and two empirical papers, chapter 5 provides an overview of this thesis. Additionally, in this chapter, the practical implications, research limitations, and directions for research in the future are included.

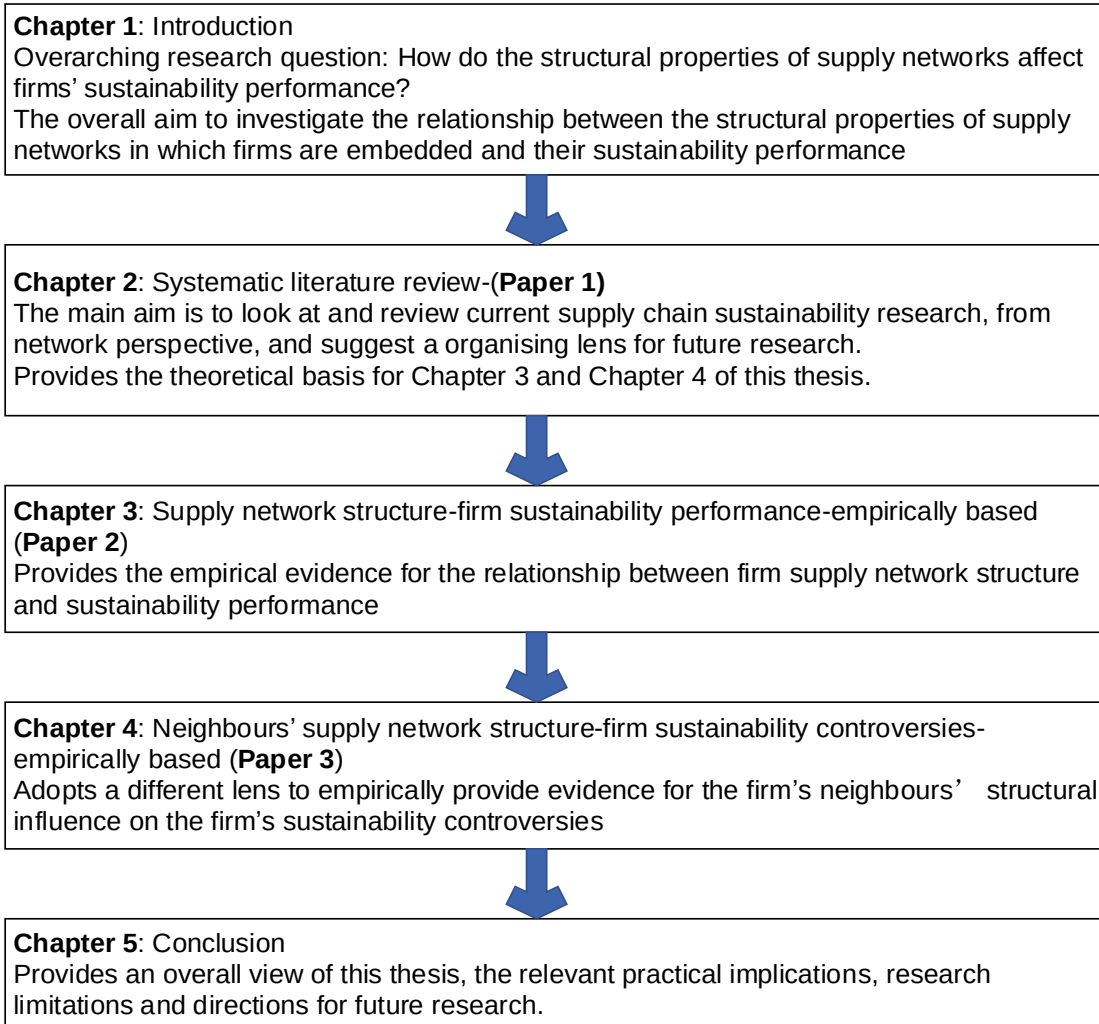


Figure 1-2 Thesis structure

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2 The role of networks in supply chain sustainability performance: a systematic review and agenda for future research

Abstract

The purpose of this paper is to systematically review, synthesise and critically evaluate the current position of scholarly studies on supply chain sustainability from a network lens as well as providing an organising lens for future scholarship in this arena. Using an evidence-based approach, this study systematically reviewed 52 articles from 17 peer-reviewed international journals related to the network lens in supply chain sustainability between the Year 2003 and Year 2018. This paper distinguishes two prevailing network properties as the salient drivers of sustainability performance in supply chains, namely relational and structural properties. The relational properties include various collaborative arrangements among multiple supply chain members as well as the governance mechanisms that support and sustain interactions among participating actors in achieving sustainability. The structural properties, on the other hand, focus on the patterns of supply chain relationships that could influence environmental and social dimensions of sustainability. Additionally, the review paper unravels an interactive effect of structural and relational properties on sustainability performance in supply chains. This study also enriches the extant understanding of the role of networks in supply chain sustainability by identifying different network attributes that influence the sustainability performance in supply chains. By synthesising the current conceptual and empirical literatures, this review provides an original, more robust understanding of different units of analysis in investigating the role of network in sustainability performance in supply chains.

Keywords: Network, Supply chain sustainability, Systematic literature review, Social network analysis

2.1 Introduction

Supply chain sustainability refers to companies across supply chains that manage the environment, social and economic impacts throughout the life cycles of products and services. Specifically, it involves the "management of material, information and capital flow as well as cooperation among companies along the supply chain taking goals from the three dimensions of environmental, social and economic into account" (Seuring & Muller, 2008, p. 1700). Given the large and increasing number of actors involved – i.e. design, production, and delivery – with the products and services, sustainability extends outside the boundaries of one firm. Therby, firms are more and more engaging in, investing in, as well as developing their relationships with their external upstream and downstream actors to measure and manage the sustainability impacts (Chen et al., 2017). The roles of supply chain collaboration in general (Cao & Zhang, 2011; Vachon & Klassen, 2008) and the specific aspects of supply chain relationships such as information sharing (Khan et al., 2016), trust (Cheng et al., 2008), and power (Chkanikova, 2016) in driving sustainability performance have been extensively studied in the literature. While research has largely focused on the dyadic relationships, in recent years a growing number of studies has started to emphasise the significance of a network lens (Borgatti & Li, 2009; Kim et al., 2011) in explaining and investigating supply chain sustainability (Tate et al., 2013).

Extant studies have underlined the cruciality of the broader supply network, in which the firm and its direct supply chain relationships are embedded, in driving the sustainability performance across the supply chain. While the focal firm has very little control over the suppliers' unsustainable behaviours when the suppliers are beyond the first tier, external stakeholders, such as environmentally and socially sensitive consumers, often hold the focal firm to account for the sustainability impact of finished products and services including the environmental and social impact of upstream and downstream actors (Hartmann & Moeller, 2014). Indeed, companies such as Apple or Tesco have been reported for a variety of sustainability violations, i.e. ranging from water contamination in finished products to unsatisfactory labour conditions in raw

material production (Choi & Linton, 2011; Roscoe et al., 2016). Extant studies suggest that the lack of abundant information on the sustainability activities and performance of these lower tier suppliers could harm the focal firm's sustainability performance (Hofmann et al., 2014). Specifically, recent research suggests that the hidden suppliers working for multiple buyers are often reluctant to share such information out of fear of being eliminated from the supply chain (Busse et al., 2017).

Concentrating on the patterns of connectivity in the supply network, recent studies have further theorised that the patterns of supply chain relationships influence firms' and their networks' sustainability behaviour and performance (Frostenson & Prenkert, 2015). Specifically, previous research has highlighted the role of firms' unique positions within the broader network-level connectivity patterns in driving their environmental and social sustainability performance. For instance, studies suggest that firms are more likely to embrace environmental standards or adhere to ethical codes of conduct during processes of sourcing and production when rooted in highly dense supply networks that receive more monitoring from multiple actors (e.g. Beckman et al., 2009; Vurro, et al., 2009).

Whilst the concept of networks prevails as a common underpinning theme that connects these findings, present literatures as a whole lacks both a synthesis of major findings and a reflection of the current development of this area. Particularly absent, still, is a thorough methodical, theoretical expression of how all the network properties of inter-connected firms in supply chains emphasise the sustainability performance of embedded firms and networks. Specifically, the literature falls short of providing a clear distinction among these units of analysis where the role of network properties in sustainability performance is investigated. Hence, this paper aims to systematically review and evaluate the current position of research in relation to supply chain sustainability, from a network perspective, to deliver an organising lens for future research in this arena. In light of this, the two review questions are therefore addressed as follows:

RQ1. What network properties are examined in relation to sustainability performance in supply chains?

RQ2. How do network properties affect the sustainability performance of firms and networks in supply chains?

Further contribution to the existing literature is taken as follows: a transparent and replicable systematic literature review (SLR) is undertaken, acknowledging dominant scholarly discussions in driving supply chain sustainability from a network lens, to give assessments of the scientific status of this field. In particular, the study also extends the understanding of the role of network in supply chain sustainability by identifying different network attributes that influence the sustainability performance in the supply chain. Specifically, I distinguish relational and structural network attributes and examine their individual and interactive effects on both environmental sustainability and social sustainability in supply chain. Additionally, the synthesis of the recent conceptual and empirical literatures has provided this review paper with an original and better understanding of different units of analysis regarding the role of network in sustainability performance in supply chain. Lastly, the author suggests several avenues for progressing the future studies in this area.

The structure of this paper is organised as follows. First, the SLR methodology is discussed in relation to the review process, the sample selection, and analysis. I then provide the description of the sample articles in the form of descriptive analysis. A thematic analysis is further incorporated to identify patterns that synthesise the relationships between network properties and sustainability performance within the supply chain. Following the thematic analysis, a set of propositions is presented articulating the various facets of this relationship, before concluding with a discussion of this review paper's original contributions to theory and an examination of its implications for practice and for areas of future work.

2.2 Methodology

To properly tackle the review questions, this study adopts an SLR approach. The approach uses a transparent and iterative review process that is reproducible and seeks to illustrate an organised synthesis of the literature (Tranfield et al., 2003). Unlike the traditional review methods, this approach uses an all-encompassing search and analysis framework, allowing researchers to gather the relevant data

from a range of knowledge bases and combine them to provide further understanding regarding the field (Smart et al., 2017). The research particularly follows Tranfield et al.'s (2003) key steps for systematic reviews, which will be explained in turn.

2.2.1 Locating studies

The literature search, executed across the Scopus, EBSCO, and ABI/INFORM databases, included multiple combinations of a range of keywords reflecting the essential phenomena of interest (i.e. sustainability, supply chain and network). The initial scoping stage was undertaken to distil the relevant keywords and construct the search strings (see Table 2-1). The three electronic databases together provided a comprehensive coverage of the research topic. The three search strings generated an initial sample of 2,567 articles and excluded the duplication of 576 articles without assessing the quality of articles. The results of numbers of articles ran differently in the three databases: the sample included 975 articles from the Scopus database, 773 articles from the EBSCO database and 859 articles from the ABI/INFORM database, respectively.

Table 2-1 Keywords and search strings

Key Subject	Related Keywords	Search String
Sustainability	Sustainability OR Environment OR Corporate Social Responsibility OR Green	("child* labour*" OR discriminat* OR ethic* OR "human* right" OR "work* welfar*" OR "employee welfar*" OR sustainab* OR "environment* W/10 practices" OR green OR "social* responsib*" OR recycl* OR "carbon footprint")
Supply Chain	Supply chain OR Supply network	(suppl* OR logistics OR "demand chain")
Network	Network OR Social Network OR Embeddedness	(network OR "structural properties" OR alliance OR interaction OR embed* OR "multi* tier" OR triad* OR "graph theory" OR inter-organi?ation* OR collaborat* OR "cross-sector" OR partners* OR "inter*firm")

2.2.2 Study selection and evaluation

The stage of this selection and evaluation process filtered articles further, a distilling informed by the inclusion and exclusion criteria, including article relevance to the review questions in Table 2-2. After screening the titles and abstracts of the selected articles, 1,605 articles were rejected as they lacked either focus on two main sustainability dimensions or lacked a network perspective in the examination of supply chains sustainability. The remaining 406 articles were considered to be valid for full-text screening. By way of the research rigour and relevance criteria, the remaining sample of articles was reduced to a final sample of 52 articles from 17 journals; four additional articles were sourced from previous authors' cross-referencing and, thus, added to the review list. These results were subsequently analysed, both descriptively and thematically, after much consideration, and will be described in turn.

Table 2-2 Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Date	From 1987 to 2018	Before 1987, After 2018
Source Type	Peer-reviewed journals	All other journals not listed
Language	English	Non-English
Access	Full-text	Non-full text
Article Type	Published articles or articles in press in scholarly journals	Conference articles, News, Magazines, etc.
Quality	Research originality, significance, and quality are considered world leading, e.g. articles selected from the Chartered Association of Business Schools (known as	Research originality, significance, and quality only meet acceptable and normal scholarly standards, e.g. articles sourced from CABS

	CABS) Academic Journal Guide 2018:	Academic Journal Guide 2018:
	Articles from journals rated 4* (i.e. journals of distinction), 4, and 3.	Citation impact factor is below 4 from 2-rated journals.
	Citation impact factor is above 4 from 2-rated journals.	Articles from 1-rated journals.
Relevance	1. Subject area is located in business management 2. Articles that address the review questions associated with research themes, and identified themes (i.e. supply chain, network, sustainability)	1. Not in the area of business management 2. Articles are irrelevant to the research themes, and network relationships falls under the dyadic level.

2.2.3 Data extraction and synthesis

The dataset culled from the selected 52 articles was heterogeneous and sourced from a combination of theoretical and empirical (i.e. quantitative and qualitative) scholarships. This study then adopted an integrative and qualitative approach to identify patterns that ultimately synthesise constructs and their relationships (Smart et al., 2017). Undertaking this approach enabled the author to review the extensive information from the selected 52-article sample and organise it in a conceptually novel way (Watson et al., 2018). In addition, a descriptive and thematic analysis that identified patterns that synthesise constructs and their relationships was undertaken. For instance, the relevant findings were accordingly interpreted and transformed into flowcharts, both to elicit relevant themes and for the sake of the author's own feedback. A clustering of these data was then cross validated by the author before it reached an agreement. The following sections presented the key themes that emerged from the review of articles. Figure 2-1 shows the final summary of this systematic selection process.

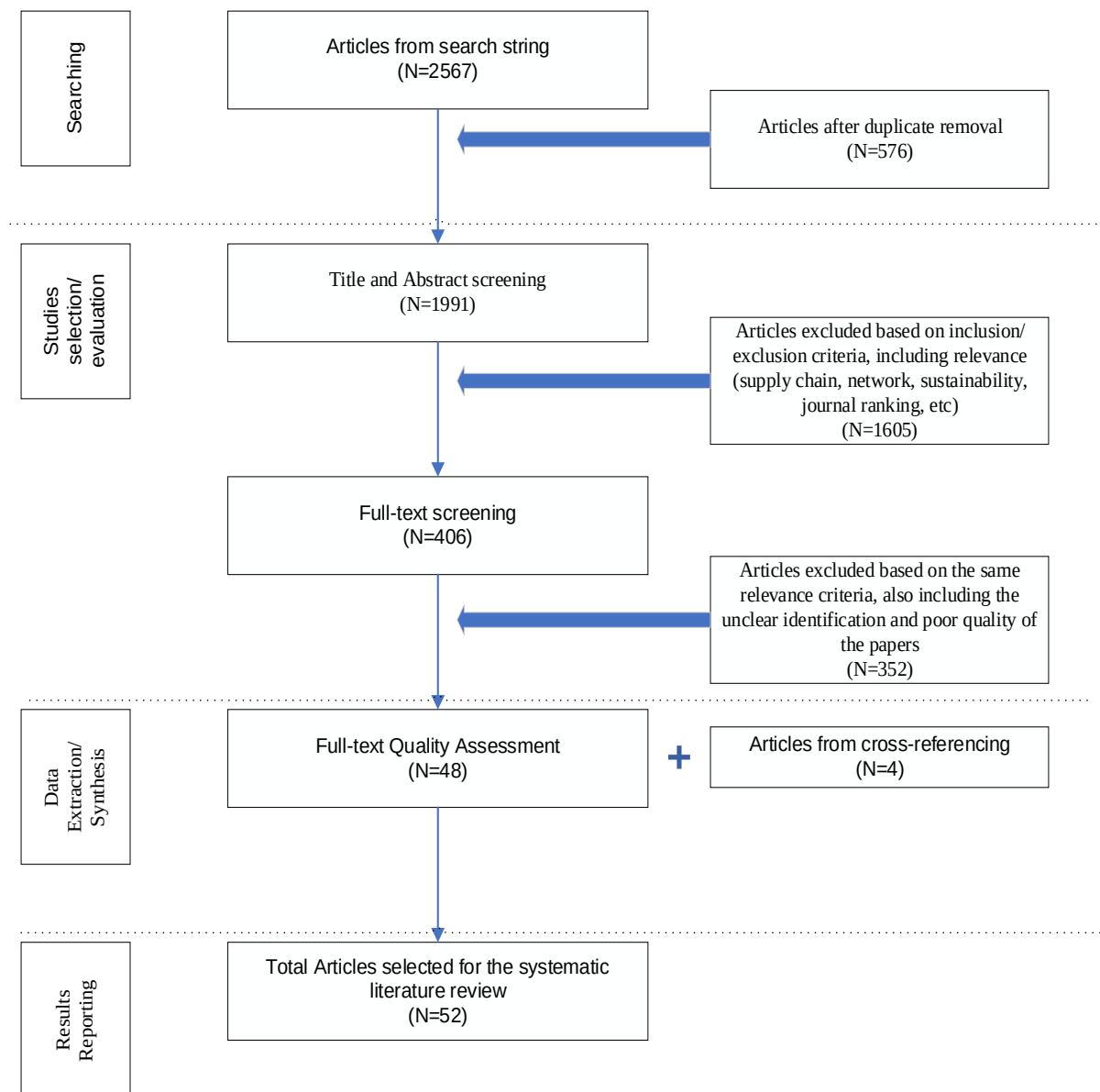


Figure 2-1 Summary diagram of the article selection process

2.3 Descriptive analysis: characterising the sample

2.3.1 Journal distribution

In line with the SLR results, Figure 2-2 is illustrative of basic journal characteristics, i.e. journal title, ranking, quantity of articles published on each journal, and the quantity of total articles published over time. As stated, this research's sample consists of 52 articles drawn from 17 different journals that are situated widely across different journal rankings (i.e. 2018 CABS journal ranking guide). Journal articles sourced from 3-rated journals were ranked with the

highest quantity at 34 out of 52 articles (65 percent), whilst only 8 and 3 account of the 52 included articles were drawn from 4- and 4*-rated journals, respectively. In a further note of segregation, *Journal of Cleaner Production* has the highest numbers of articles, followed by *Journal of Business Ethics* and *Supply Chain Management: An International Journal* and *Journal of Supply Chain Management*. In addition, the trendline of the total articles' quantity demonstrated that mounting interest exists towards scholarly research in this specific realm, with a stable growth of 39 articles published in the recent 5 years, from 2014 and onwards.

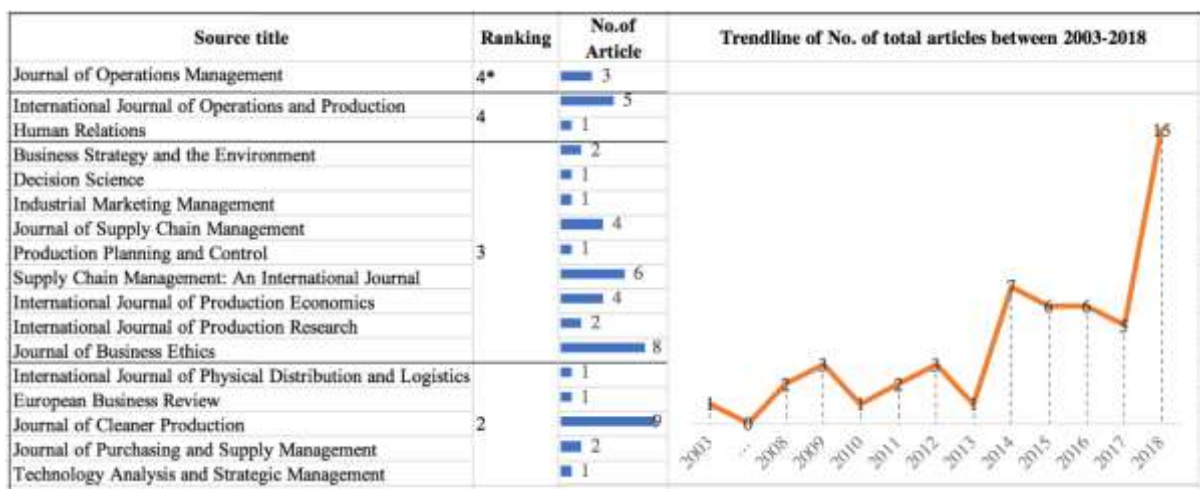


Figure 2-2 Journal distribution

2.3.2 Publication by geography

Among the research partaken, all are internationally situated in the academic community with lead authors located in 19 countries (Figure 2-3) – most originating from developed countries, particularly the UK (11 articles), the US (5 articles), Germany (4 articles), and The Netherlands (4 articles); of the involved developing countries, China contributed the second-most to this study's research sample (6 articles) following the UK. In line with the highly distributed output across countries, publication quantities of these articles may indicate that sustainability-oriented supply networks in developed economy countries have garnered more awareness than those in developing economy countries.

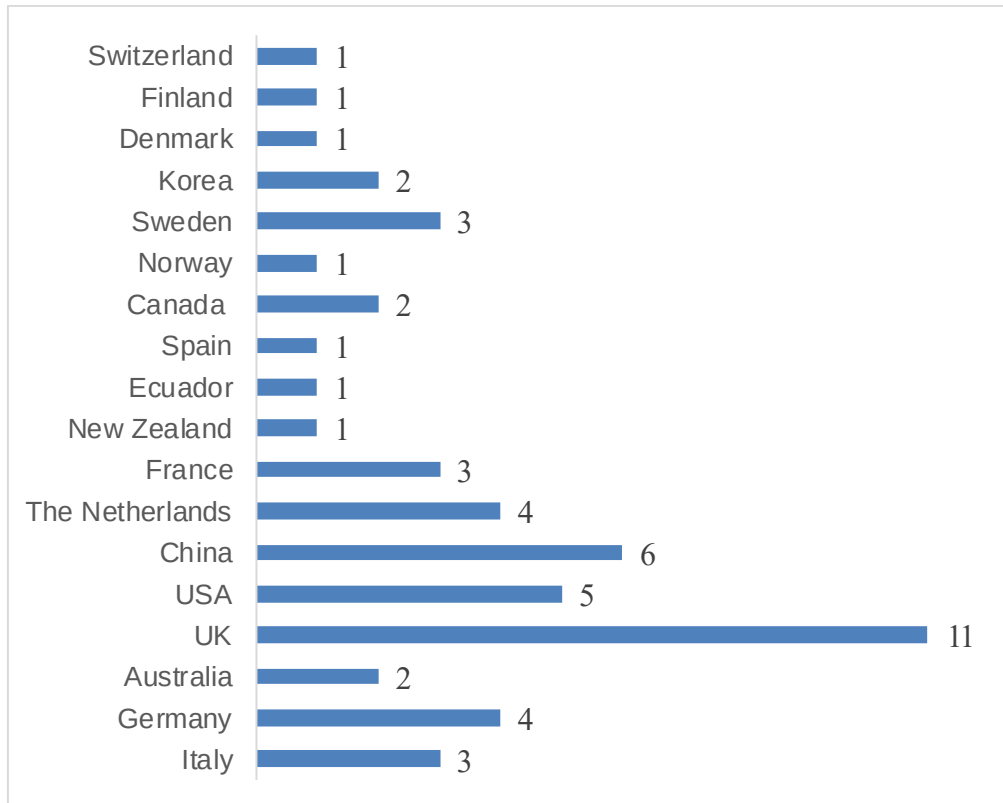


Figure 2-3 Geographical distribution

2.3.3 Nature of studies and methodology

Figure 2-4 observes that the number of empirical studies (41 articles) outweigh the theoretical studies (11 articles), which is indicative of the dominant output type. Consistent with that, Figure 2-4 also showcases the methodology largely adopted in the empirical studies, which includes expert interview, mathematical modelling, case study, survey, and “mix” methods (i.e. a mix of case study and survey, or case study and interview, or survey and interview in spite of the qualitative-quantitative dichotomy). From this study’s sample, most empirical research adopted mix methods (16 articles) followed by those involving case study (13 articles), and survey (8 articles). In comparison, mathematical modelling was found to be of rare use, at least among the selected studies, with only two articles (Sarraj et al., 2014; Xiao et al., 2012) highlighted. The rationale behind this small number might be that, although the method is more precise, such modelling requires large amounts of data to conduct evaluation and it is mainly based on precise assumptions (Chen et al., 2017).

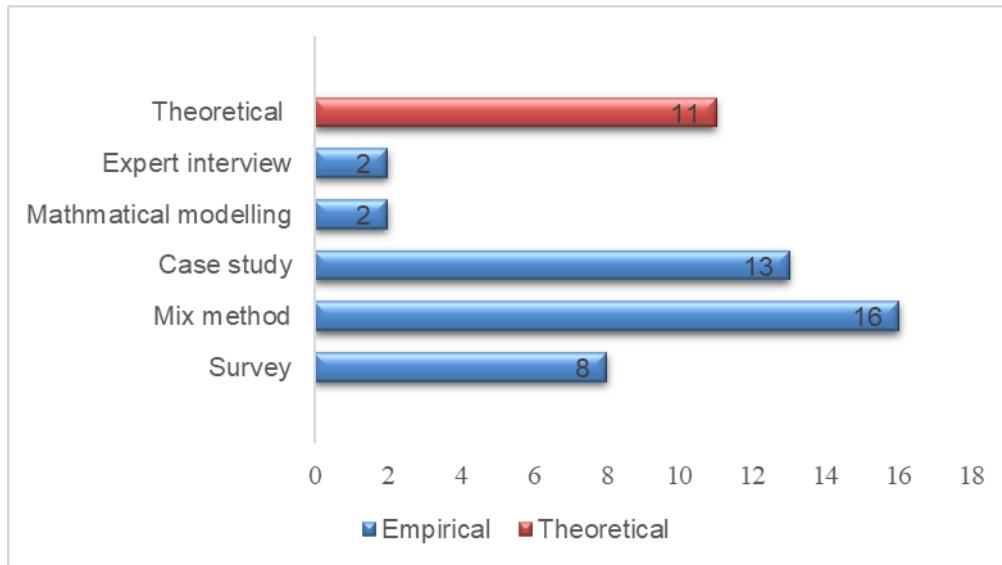


Figure 2-4 Nature of studies and methodology

2.3.4 Sector and industry type

Figure 2-5 reviews the selection of the 52 articles and picks up the articles that have been undertaken in the empirical setting. A closer qualitative analysis of the empirical research illuminated that all revolve around two categories in a conglomerate: manufacturing sector and the non-manufacturing sector. The former sector is a blanket term under which are manufacturing-specific, textile, processing, packaging, automotive, and electronics, while the latter includes industries that rather focus on services, housing, consumer product, retail, agriculture, and high-technology (Prajogo et al., 2014). Review notes that manufacturing sector research still dominates the general direction of the sample literature with around 49% (21 articles) in total. By contrast, the non-manufacturing sector encompasses only 28% (12 articles). In terms of industry output, articles may be credited to 12 industries indicating a broad industry interest in this particular research.

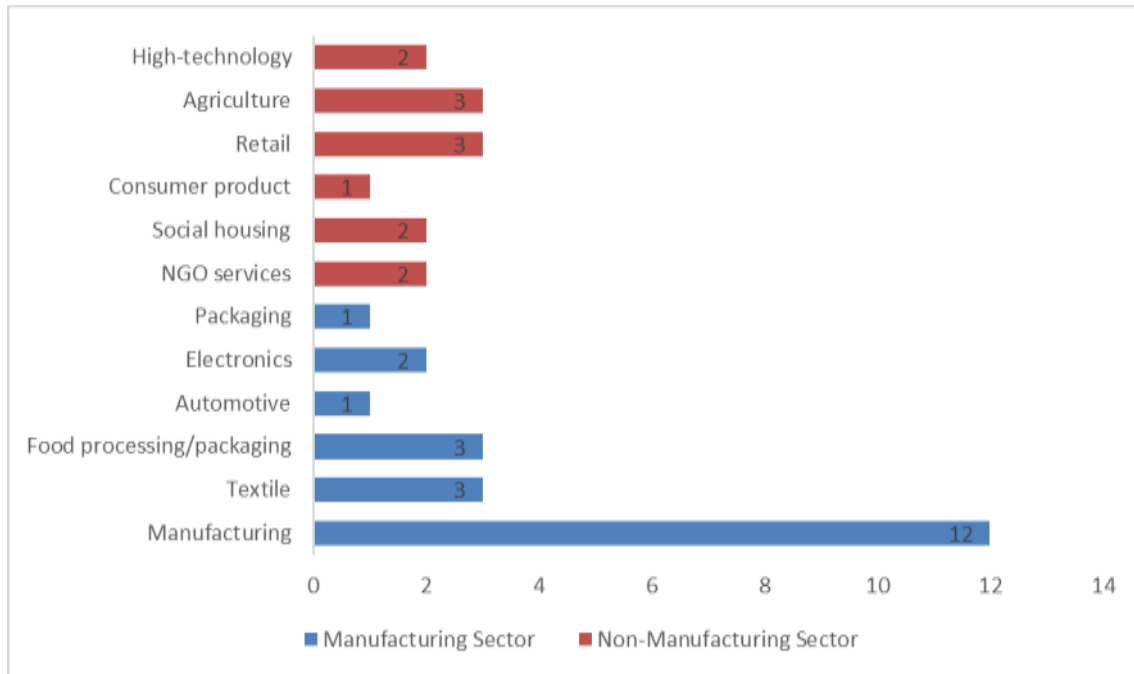


Figure 2-5 Frequency of industry/sector between 2003 and 2018

2.3.5 Underpinning theories

Underpinning theories offer a theoretical understanding of how the questions directing a scholarly study are examined. Table 2-3 presents an overview of theories that have been adopted at least two or more than two times in the selected articles.

Table 2-3 details network theory and stakeholder theory as the most frequently cited (6 times) theories in the last ten years of publishing. For network theory, this number increased by a factor of four in the most recent five-year period within the research realm. Drawing upon the resources and information flow among network actors, network theory provides a broader lens to understand the role of different actors in achieving the common goals (i.e. sustainability) in the supply network. For instance, it may provide opportunities for organisations to facilitate information and resources synergies with their business partners beyond the typically dyadic collaborative relationships towards a more thorough and effective implementation of sustainable practices (Tate et al., 2013). Stakeholder theory scholarship saw a similar increase – i.e. by a factor of five within the 2013 - 2018 period – a rise indicative of growing concerns of influential stakeholder pressures

(customers, non-government organisations (NGOs), governments, etc.) towards organisations' practices. Stakeholder theory may also provide an important lens to investigate the impact of involvement of different actors on achieving business practices (Chen et al., 2017). Both network theory and stakeholder theory help provide a theoretical lens for network actors to consider at a broader level towards their practices.

In addition to the above, Table 2-3 displays various theories that have been cited appropriately, such as complex adaptive system theory, social capital, social network theory, natural resource-based view, relational view, institutional theory, resource-dependence theory, as well as transaction cost economics theory. The adoption of these theories might suggest that a firm's sustainable competitive advantage is saliently linked to its resource base (Chen et al., 2017).

Table 2-3 Theories adopted with two or more frequencies

Theory	Frequency of use	5-year Time period	
		2008-2012	2013-2018
Network theory	 6	2	4
Stakeholder theory	 6	1	5
Complex adaptive system theory	 5	1	4
Social network theory	 4	0	4
Social capital theory	 3	0	3
Natural resource-based view	 2	0	2
Relational view	 2	0	2
Institutional theory	 2	2	0
Resource-dependence theory	 2	0	2
Transaction cost economics theory	 2	1	1

2.4 Supply chain sustainability performance: dimensions, conceptualisations, and units of analysis

The scholarly work adopting a network perspective in investigating supply chain sustainability has increasingly shifted its focus to the non-economic dimension of sustainability (Chen et al., 2017). In measuring the non-economic performance of sustainable supply chains, extant studies have largely focused on the two

dimensions of environmental and social. To define these briefly: The environmental dimension refers to the impacts of supply chain activities, which include design, sourcing, manufacturing, delivery, and end-of-life management to the environmental resources (Srivastava, 2007); the social dimension, on the other hand, emphasises the management of social resources that are involved in supply chain activities including people's skills and abilities, institutions, relationships, and social values (Ashby et al., 2012). Figure 2-6 illustrates the distribution of this study's sample according to the examined sustainability dimensions. As illustrated, most papers have examined the environmental dimension of sustainability, with the second-most evaluating both environmental and social dimensions both together. In terms of solely examining the social dimension, as it relates to measuring the performance of sustainable supply chains, only 7 articles have been published over the time span 2014–2018.

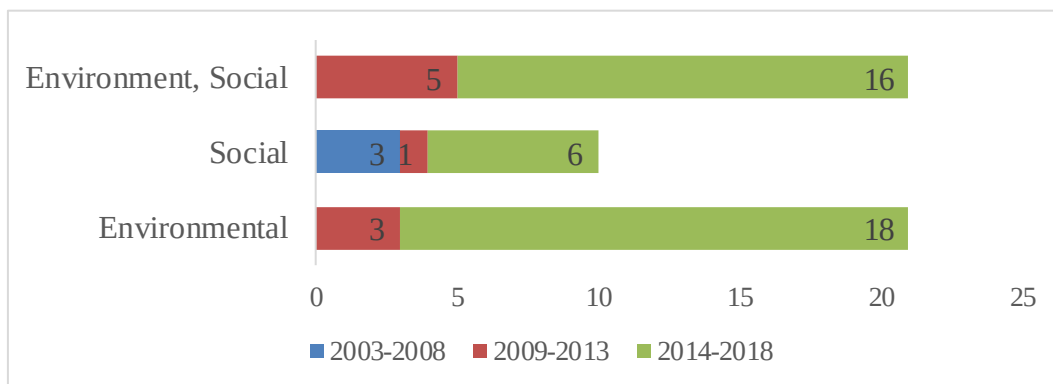


Figure 2-6 Sustainability performance in terms of different dimensions by period

In conceptualising and investigating the performance of both environmentally and socially sustainable supply chains, scholars have generally adopted two disparate approaches. These two approaches along with the specific measures adopted for the environmental and social dimensions are summarised in Tables 2-4 and 2-5, respectively. First, the sustainability performance is examined in terms of the environmental and social outcomes. Specifically, sustainability outcomes indicate the firms' relative impact on the environment and society via their internal and external processes of sourcing, manufacturing, and delivery across the entire supply chains (Miemczyk et al., 2012; Pullman et al., 2009). As one example, scholars have investigated the “outcomes for the natural

environment, such as the reduction of solid/liquid waste, emissions, consumption of resources and toxic materials, frequency of environmental accidents, an increase in compliance with environmental standards” (Tachizawa & Wong, 2015, p. 19) in measuring the performance of environmentally sustainable supply chains. Similarly, outcomes such as equal human rights, regular employment, health and safety or non-discrimination have been used as indicators measuring social outcomes (Busse et al., 2017).

Table 2-4 Supply chain sustainability performance – environmental dimension: Firm and network levels

Sustainability Measurements			Unit of analysis	
Environmental Sustainability			Focal firm	Network
	Outcome driven performance		Busse et al., 2017; Herczeg et al., 2018; Hung et al., 2014; Meinlschmidt et al., 2018; Mena et al., 2014	Marconi et al., 2017; Patala et al., 2014; Sarraj et al., 2014; Tachizawa & Wong, 2015; Marconi et al., 2017
	Process driven performance	Practice	Use of environmental management system; Green supplier management programmes; Sustainable supplier selection; Ethical sourcing; Use of recycling facilities; Use of product label	Dou et al., 2018; Golini & Gualandris, 2018; Tachizawa & Wong, 2014; Meinlschmidt et al., 2018; Vurro et al., 2009; Xiao et al., 2012; Gong et al., 2018; Van Bommel, 2011
				Megdadi et al., 2017; Tate et al., 2013; MacCarthy & Jayarathne, 2012

	Compliance to environmental sustainability codes of conduct/ standards/regulations/laws	Golini & Gualandris, 2018; Bush et al., 2015; Hartmann & Moeller, 2014; Liu et al., 2018; Meinschmidt et al., 2018; Oosterveer, 2015; Lee & Koh, 2009; Wilhelm et al., 2016; Wu & Pullman, 2015; Xiao et al., 2012	Nair et al., 2016; Tate et al., 2013; Frostenson & Prenkert, 2015; Alvarez et al., 2010; Meqdadi et al., 2017; Meqdadi et al., 2018; Tachizawa & Wong, 2015
	Engage third party (e.g. audit firms) to improve environmental sustainability	Tachizawa & Wong, 2014	Meqdadi et al., 2018; Meqdadi et al., 2017
	Environmental innovations (including product and process eco-innovations)	Roscoe et al., 2016; Prajogo et al., 2014	Patala et al., 2014; Nair et al., 2016; Tate et al., 2013
Behaviour	Perceptions of implementing environmental initiatives; Perceptions of sustainability risk/environmental accidents	Gong et al., 2018; Busse et al., 2017; Villena & Gioia, 2018	Tachizawa & Wong, 2014
	Willingness to develop green capabilities	Dou et al., 2018	

Table 2-5 Supply chain sustainability performance – social dimension: Firms and network levels

Sustainability Measurements				Unit of analysis	
				Focal firm	Network
Social sustainability	Outcome driven performance		Equal human rights, human treatment; Regular employment; Non-discrimination; Child labour reduction; Forced, compulsory, bonded labour reduction; Freedom of association and collective bargaining; Remuneration, benefits, wages; Regular working hours; Workplace safety and health	Busse et al., 2017; Bush et al., 2015; Johnson et al., 2018; Saunders et al., 2017; Herczeg et al., 2018; Meehan & Bryde, 2015; Rodríguez et al., 2016; Saunders et al., 2017; Roscoe et al., 2016; Gong et al., 2018	MacCarthy & Jayarathne, 2012
	Process driven performance	Practice	Encourage suppliers/employees to adopt CSR initiatives; Encourage and develop suppliers to behave sustainably; Educate consumers for environmental protection	Busse et al., 2017; Gong et al., 2018; Meehan & Bryde, 2015	MacCarthy and Jayarathne, 2012; Fontana & Egels-Zandén, 2018

	Compliance to the reported CSR initiatives/ethical codes of conduct; Use of third-party certifications	Airike et al., 2016; Castka & Balzarova, 2008; Chen, 2018; Lim & Phillips, 2008; Liu et al., 2018; Meinlschmidt et al., 2018; Roberts, 2003; Svensson et al., 2018; Vurro et al., 2009	Frostenson & Prenkert, 2015; Alvarez et al., 2010; Fontana & Egels-Zandén, 2018
	Product-label concerning sustainability (e.g. fair trade)	Van Bommel, 2011	
	Train workers to implement sustainability	Rodríguez et al., 2016	
Behaviour	Improve employee's understanding and build vision towards social sustainability and promote social values and goals Perception of risk of being penalised by not complying with labour regulations; Social reputation harm	Gong et al., 2018; Meehan & Bryde, 2015; Meehan & Bryde, 2015 Villena & Gioia, 2018	Tachizawa & Wong, 2014

Second, the sustainability performance is examined in terms of internal and external environmental and social *processes* that firms adopt to achieve sustainability across their supply chains (Gimenez et al., 2012). Particularly, this study's results suggest that such processes often manifest through various practices that firms adopt or behaviours they exhibit to showcase a move toward sustainability. Regarding the practices, existing research has identified environmental-friendly product design, waste management, recycling, and ethical sourcing as tangible variables to measure a supply chain's environmental sustainability (e.g. Golini & Gualandris, 2018; Tachizawa & Wong, 2014). Additionally, social practices, such as compliance to corporate social responsibility (CSR) initiatives, codes of conduct or suppliers' monitoring and auditing, have been adopted as further means of relevant measurement (e.g. Airike et al., 2016; Meehan & Bryde, 2015).

Furthermore, scholars have highlighted the behavioural aspects through examination of the role of actors' values, attitudes, beliefs, and sense of responsibility in deliberating actions to enact in achieving sustainability (De Clercq et al., 2018). For instance, firms' perceptions of environmental initiatives, as well as their willingness to either develop green initiatives or promote sustainability values, and the building of visions, appeared as variables in measuring the environmental and social dimensions of sustainability performance (Dou et al., 2018; Rodríguez et al., 2016). Furthermore, scholars have highlighted the perceived sustainability risk in accounting for the firm's assessment of environmental uncertainty or potential harm to social reputation, which may occur when sustainability goals are violated.

In investigating the sustainability performance in supply chains, extant studies have largely adopted two units of analysis: firm-level and network-level (see Tables 2-4 and 2-5). Firm-level analysis often refers to the supply chain of an individual focal firm that is involved in the design and delivery of a product or service (Seuring & Muller, 2008). Network-level investigation, conversely, often relates to the entire supply network that produces the final product or service (Tachizawa & Wong, 2015). With regards to this study's specific sample, the firm-

level studies investigated the role of networks in supply chain sustainability from an individual firm's viewpoint ruling the supply chains, while network-level investigations adopt a bird's eye view as a means to examine the sustainability performance of supply network members collectively. For instance, while a focal firm-level study would focus on the internal and external sustainability impact of a single firm across its supply chain, network-level studies would examine the aggregative sustainability outcomes for a group of firms. In terms of quantity, the articles with a single focal firm as the unit of analysis dominated the study sample (35 articles) with the number of network-level studies registering at only 13 articles (see Figure 2-7).

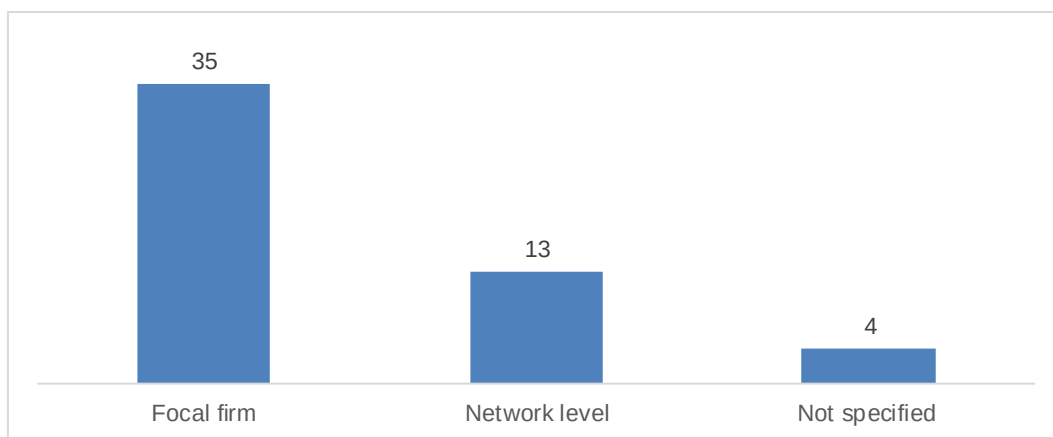


Figure 2-7 Unit of analysis

2.5 The relationships between network properties and supply chain sustainability performance

This study differentiates between two prevailing network properties, i.e. relational and structural, in attaining sustainability performance in supply chains. The relational properties include various collaborative arrangements among multiple supply chain members as well as the governance mechanisms supporting and sustaining interactions among participating actors in achieving sustainability. The structural properties, on the other hand, focus on the architecture or overall patterns of supply chain relationships that potentially affect the environmental and social aspects of sustainability. In its review of both aspects, this study suggests an interactive effect of structural and relational properties on sustainability performance in supply chains. Framing the following section, the study provides

analysis of findings and a description of how each network property influences the sustainability performance of firms and networks in supply chains.

2.5.1 Network relational properties and sustainability performance in supply chains

2.5.1.1 Network-level collaboration

The reviewed studies have highlighted the role of collaboration beyond dyads in achieving the sustainability performance in supply chain (Table 2-6). While different labels, such as multi-stakeholder collaboration (Svensson et al., 2018), cross-tier collaboration (Mueller et al., 2009) or cross-sector partnerships (Johnson et al., 2018), have been used by scholars, this strand of literature has commonly investigated situations in which three or more autonomous actors from across the supply chain work jointly to plan and execute a common sustainability goal (i.e. for some forms of mutual expectations and benefits) (Hung et al., 2014). These autonomous actors anticipating the collaboration could be from private, public or NGO sectors. I refer to these settings where any group of three or more autonomous actors interact and join forces in addressing the sustainability goals as network-level collaboration. The existing literatures have also investigated the role of network-level collaboration in relation to supply chain sustainability performance at both firm- and network-levels. Specifically, the review of literature has revealed that network-level collaboration affects firm- and network-level supply chain sustainability performance through developing collective capability and collective behaviour.

First, extant studies suggest that network-level collaboration enables the participating actors to develop collective capabilities and make supply chain sustainability ends meet both for firms and whole networks. Specifically, in the supply chain context, compared with tier-one suppliers, dispersed lower-tier suppliers often lack strong sustainability capabilities. In particular, given the geographical dispersion of the supply network, its embedded firms may confront the problem of being too isolated or over-specialised to adopt or call for new and more environmentally and socially sustainable practices (Golini & Gualandris, 2018). Network-level collaboration involves resource sharing and exchange

among multiple supply chain actors. The resource sharing could occur through multiple forms of channels and roots for acquiring different resources such as knowledge, expertise, employee, assets, etc. (Lim & Phillips, 2008). For instance, certain studies suggest that the sharing of information of technological expertise or employees among actors from multiple supply chain tiers could facilitate the joint development of environmental sustainable solutions (Marconi et al., 2017). The mobilisation of resources among multiple actors would create a shared communication platform that would enable the participating members to reach a collective understanding of each other's requirements, limitations, and capabilities (e.g. the region- or industry-specific sustainability requirements or technological locks) (Golini & Gualandris, 2018; Lee & Koh, 2009).

The importance of network-level collaboration in addressing the sustainability goals have been emphasised among different type of actors by prior scholarship. For instance, Meehan and Bryde (2015) examined the adoption of sustainable procurement and found that even firms competing for the governmental contracts are more likely to form the procurement consortia, due to the fact that the individual actors often lack the resources and skills required to achieve the set goals. Similarly, private firms may seek help from the public and NGOs in the process of collectively identifying responsible sourcing practices, particularly in cases where they lack technical capabilities (Airike et al., 2016; Castka & Balzarova, 2008). Thus, network-level collaboration would enable participating firms to draw on the strengths and compensate for the weaknesses that exist in the group to build collective capabilities that could positively contribute to individual member sustainability, as well as the collective sustainability performance often in the form of joint product solutions (MacCarthy & Jayarathne, 2012).

Second, prior research has suggested that network-level collaboration promotes a collective behaviour towards sustainability among the participating firms that will positively drive the sustainability performance in supply chains (e.g. Fontana & Egels-Zandén, 2018). In particular, scholars have highlighted that in addressing the supply chain sustainability goals, firms face the challenge of engaging

multiple actors from different tiers (Lu et al., 2018; Tachizawa & Wong, 2015) – a domain which often sees conflicting sustainability ambitions and objectives (Villena & Gioia, 2018). Network-level collaboration provides a platform through which the participating actors can build shared values, vision, and attitude towards sustainability. Attesting to this notion is the work of Svensson et al. (2018) and Roberts (2003), who have likewise suggested that knowledge and information sharing among buying firms, suppliers, and lower-tier suppliers triggers the transfer of embedded CSR values from the buying firms to their multi-tier suppliers, leading to suppliers' ethical commitment to CSR initiatives. The form of shared values and of sustainability initiatives would enable the embedded firms to engender greater understanding and a more lucid vision toward realising the focal firm's sustainability initiative, which may in turn reduce the perceived risk of chain liability when a focal firm often holds accountability for the unsustainable supplier's behaviour. Similarly, the shared values of complying to the generalised standards/codes of conduct would, therefore, help guarantee the lower-tier suppliers do the same when faced with controversial issues in sustainable certification and ethical sourcing, thus positively driving the network-level sustainability performance (Johnson et al., 2018). Thereby, it is proposed:

Table 2-6 Network-level collaboration and sustainability performance in supply chains

Network-level collaboration			Unit of analysis	Sustainability performance	
Actors	Author/Collaborative arrangement description			Environmental dimension	Social dimension
Collaboration with private firms	Manufacturer, supplier, and the end-user	Lee & Koh, 2009: Multilateral resource sharing (i.e. information, new ideas/designs), co-product development	Focal firm	✓	✓
	Lead buying firm, multiple suppliers, subcontractors	Lim and Phillips, 2008: Information sharing, joint product development, sharing responsibility in R&D and production			✓
	Multinational plants	Golini and Gualandris, 2018: Information sharing, employees/network performance systems sharing, innovation sharing, database sharing		✓	
	Multi stakeholders	Svensson et al., 2018: Knowledge sharing		✓	✓
		Roberts, 2003: Information sharing			✓
		Hung et al., 2014: Knowledge sharing of green practices		✓	
		Herczeg et al., 2018: Jointly developing processes and products, information/knowledge/experience sharing, collective learning		✓	✓
	Procurement consortia	Meehan and Bryde, 2015: Knowledge/information/expertise sharing, collective and shared visions		✓	✓

	Cross sectors	Johnson et al., 2018: Information sharing and transfer	Network	✓	
	Multiple suppliers	Fontana and Egels-Zandén, 2018: Information sharing, collective behaviour			✓
	Retailers, agents, the prime manufacturer, the fabric and accessory suppliers, and logistic partners	MacCarthy and Jayarathne, 2012: Jointly developing environmental solutions		✓	✓
	Actors from different supply chain steps	Marconi et al., 2017: Data sharing		✓	
	Third-party logistic provider, multiple suppliers, retailers	Sarraj et al., 2014: Logistics capacity sharing		✓	
Collaboration with public & NGO actors	Leading firm, NGOs, multiple stakeholders	Airike et al., 2016: Sharing responsibilities, collective learning	Focal firm		✓
	Industrial firms, governments, NGOs	Patala et al., 2014: Information/knowledge/assets/values sharing	Network	✓	
	Business firms, government	Castka and Balzarova, 2008: Sharing of technological advances and management practices			

Proposition 1 *Network-level collaboration positively affects sustainability performance at firm and network levels in supply chains through developing collective capabilities and promoting collective behaviour.*

2.5.1.2 Network governance mechanisms

Supply networks consist of complex interfirm relationships where in addressing sustainability goals, the member firms often deal with issues such as resource and power asymmetry, reduced visibility, and transparency. Thus, to achieve sustainability, it is imperative for firms to put in place appropriate governance mechanisms to support and sustain their interactions with multiple actors across the supply chain. Specifically, in a network context, the negative effects of noncooperation are potentially diffused over several partners, and one partner's uncooperative behaviour is more likely to be anonymous than in the bilateral partnership. Network governance refers to "a set of mechanisms that support and sustain collaboration among participating actors to enhance the likelihood of achieving goals" (Grandori & Soda, 1995, p. 183). Network governance distinguishes itself from dyadic level governance in that it focuses on managing the whole network involving all the interconnected actors rather than actors with whom the focal firm directly interacts.

Adopting a network perspective, prior studies have proposed several strategies for lead firms to manage their lower-tier suppliers' sustainability performance in multi-tier supply chains (Meinlschmidt et al., 2018; Mena et al., 2013; Tachizawa & Wong, 2014; Wilhelm et al., 2016). In particular, extant literature has suggested that firms adopt both formal and informal governance mechanisms in addressing the sustainability goals. *Formal governance mechanisms* refer to an explicit way by using structural arrangements to affect the network actors' behaviour towards sustainability (Tachizawa & Wong, 2015, p.22). Such arrangements could involve command structures, incentive systems, standard operating procedures, and documented dispute resolution procedures (Alvarez et al., 2010). Specifically, "the formalisation of SSCM activities can be realised through a set of codes of conduct, industry standards and formal contracts, etc." (Tachizawa & Wong, 2015, p. 22). In contrast, *Informal governance mechanisms* "govern networks

through social forms of control” (Tachizawa & Wong, 2015, p. 22). In particular, they can be realised through trust or various forms of power. At the network level, this study characterises the formal governance mechanisms as the transfer or delegation of formal contractual duties to other parties to control the direct and indirect actors. Similarly, informal governance mechanisms at the network level revolve around the diffusion of or use of any forms of social control that oblige direct and indirect actors across the supply chain to address the sustainability agenda (see Table 2-7).

Table 2-7 Network governance mechanisms and sustainability performance in supply chains

Network governance mechanisms		Unit of analysis	Sustainability performance	
Network dimensions	Author/Description		Environmental dimension	Social dimension
Formal governance	Bush et al., 2015: Standards, regulations, etc.	Focal firm	✓	✓
	Prajogo et al., 2014: The level of variation of the diffusion of environment management system within organisations		✓	
	Mena et al., 2014: Disciplines	Network	✓	✓
	Tachizawa and Wong, 2015: Industry standards, use of assessments and audits, etc.		✓	
	Gong et al., 2018: self-reporting, standards, etc.		✓	
Informal governance	Dou et al., 2018: Trust between chain members, e.g. focal company and first tier suppliers, first tier and second suppliers in the multi-tier supply chain	Focal firm	✓	✓
	Hartmann and Moeller, 2014: Trust		✓	✓
	Lu et al., 2018: Embedded trust among actors in GuanXi networks		✓	✓
	Oosterveer, 2015: Power dominance in the network		✓	
	Van Bommel, 2011: Level of innovation power of focal company's supply network		✓	✓
	Touboul et al., 2014: Power dominance in the network		✓	

Meqdadi et al., 2018: Power (exerting reward, expert power, exerting reference and legitimate power) at supply network level	Network	✓
Meqdadi et al., 2017: Power and trust on the process of sustainability spread between the company and several suppliers		✓

Formal governance mechanisms can act as an efficient tool for firms to communicate the environmental and social requirements and practices to their multiple tiers of suppliers across the entire network. Additionally, firms use formal governance mechanisms, such as contracts, to monitor the compliance of indirect suppliers often by delegating the authority to their first-tier suppliers (Tachizawa & Wong, 2015). Specifically, formal governance mechanisms are established to reduce the riskiness of managing the lower-tier suppliers' unsustainable behaviour when the sound expectations are set. For instance, Mena et al. (2014) suggested that when focal firms develop tight specifications to meet consumers' expectations, they transfer these disciplines to first-tier suppliers and entitle them to actively select and manage their lower-tier suppliers by adopting green practices such as ethical sourcing and purchasing.

Similarly, at the broader network-level, explicit industry standards, such as ISO1400, would encourage network members to make commitments to green practices. In particular, the formalisations of rules, structures, and procedures are written down to define roles and pass information. In order to drive the sustainability compliance, firms may draw on industry-wide standards to put pressure on lower-tier network members (Bush et al., 2015; Tachizawa & Wong, 2015). Firms can also identify new ways to professionalise their green practices and mitigate the risk of causing sustainability damage to the environment and society through the flow of information and knowledge (Prajogo et al., 2014). Whilst much of the extant literature has largely highlighted the positive effects of formal governance mechanisms in supply chain sustainability performance, certain scholars have advanced dissent by suggesting their weakness. For instance, Tachizawa and Wong (2015) have noted that a high level of formal control may undesirably engender high contracts and enforcement costs. Further drawbacks include the reality that formal control cannot fully address potential opportunistic behaviours, and thus will have a negative impact on network-based collaboration for sustainability.

Informal governance mechanisms may substitute or complement formal controls and act as a conduit for spreading sustainability across the various cogs of a supply network. In particular, the influential relationship characteristics, such as power and trust, enable this form of spreading. To explain further: the review of literature suggests

that trust serves as an underlying factor influencing actors' values towards sustainability as well as their behaviour to make commitment to sustainability initiatives. In particular, extant studies suggest that trusting relationships between firms' direct connections and those to whom they are not directly connected can positively contribute to firms' sustainability performance (e.g. Dou et al., 2018). For instance, Hartmann and Moeller (2014) suggested that in a multi-tier supply chain, tier-one suppliers would be willing to disclose their own supplier's information to the focal firm if their relationship is one based on trust. Similarly, tier-two suppliers would be more willing to adopt green practices that are required by the focal firm in cases where the knowledge disseminates from tier-one actors with whom they have forged long-term trusting relationships (Gong et al., 2018; Lu et al., 2018). Meqdadi et al. (2017) addended both empirical observations in providing evidence that trusting relationships accelerate the sustainability practices diffused to lower-tier suppliers; this is in contexts where the focal buying firm expected suppliers with trust to act according to its expectation for spreading the sustainability initiative. Additionally, recent research suggests that trust based relationships also enable suppliers' self-reporting, which in turn facilitates a flexible and better learning process (Gong et al., 2018) and, thereby, improves the sustainability performance.

Second, certain studies have advanced that the use of power across multiple tiers affects embedded firms capacities to address their sustainability goals (e.g. Oosterveer, 2015; Van Bommel, 2011). For example, when some lower-tier suppliers (e.g. tier two suppliers) resist adopting the sustainability initiatives launched by their focal buying firm, this buying firm may use non-coercive power exerting moral influence and putting pressure on the first-tier suppliers to demand the implementation of environmental practices from second-tiers. In additional observation, other recent studies suggest that the level of power imbalance affects the level of suppliers' compliance and engagement in sustainability. For instance, Touboulic et al. (2014) suggest that when a buyer dominates the network, they will pose more power on lower-tier suppliers, leading to more pressure on suppliers to impose their sustainability agenda. That might help mitigate the reputational and operational risks emerging from unethical and unsustainable practices (Touboulic et al., 2014). Hence, I propose:

Proposition 2. *The adoption of formal governance mechanisms (i.e. transfer or delegation of formal contractual duties to other parties to control the direct and indirect actors) as well as informal governance mechanisms (i.e. diffusion of trust and power to direct and indirect actors across the network) affecting the sustainability performance at firm and network levels in supply chains.*

2.5.2 Network structural properties and sustainability performance in supply chains

The structural properties of supply network refer to the overall patterns of inter-connectivities among supply chains members. Whilst prior studies have predominantly investigated the relative position of individual firms with respect to one another (i.e. structural embeddedness) in relation to innovation performance (e.g. Bellamy et al., 2014) or resilience (e.g. Kim et al., 2015) in supply networks, most recently scholars have begun to suggest that supply chain relationships' patterns also affect the sustainability performance of the embedded firms (e.g. Frostenson & Prenkert, 2015). Specifically, previous research has highlighted the role of firms' unique network positions such as centrality (i.e. relative importance of individual nodes in a network, Kim et al., 2011) and structural hole (i.e. lack of a direct contact between two or more network members, Burt, 2002) as well as whole network-level patterns such as density (i.e. number of total ties in the network relative to the number of potential ties) and complexity (i.e. number of network tiers, number of and the geographical dispersion of actors in each tier, Choi & Hong, 2002) in driving firms' environmental and social sustainability performance (Table 2-8).

Table 2-8 Network structural properties and sustainability in supply chains

Network structural properties		Unit of analysis	Sustainability performance	
Structural properties	Author/Description		Environmental dimension	Social dimension
Network density	Vurro et al., 2009: Degree of completeness of the ties between the actors in a network. In certain context, it also represents the interconnectedness of actors along the value chain	Focal firm	√	√
	Beckman et al., 2009: The interconnectedness of stakeholders in a network			√
	Xiao et al., 2012: only mentioned, no further clarification.		√	
Firm centrality	Vurro et al., 2009: The extent to which an organisation occupies a central position in a network. In certain context, it is also referred as the relative position of each supply chain within the network, where a higher level of centrality corresponds to a more prominent intermediary role within the network	Focal firm	√	√
	Beckman et al., 2009: The position of a particular focal firm in the network relative to other stakeholders			√
Buying firms' structural supply network complexity	Meinlschmidt et al., 2018: The vertical and horizontal complexity of supply networks can be affected by the number of upstream tiers and the suppliers operating at the same tier level; In addition, spatial complexity is defined as the dispersion of tiers across various countries and locations	Focal firm	√	√
Structural hole	Roscoe et al., 2016: Focal firms that establish weak ties to suppliers, which help to bridge structural holes in industrial supply network.	Focal firm	√	√
	Rodríguez et al., 2016: NGO's bridging capability			√

	Saunders et al., 2017: Brokerage exchanges help bridge the structural holes between a focal firm (Actor A) and an intended target firms (Actor C)		√
Structural embeddedness of the supplier network	Tate et al., 2013: To address the configuration of the network, it is stated that the presence or absence of network ties between actors as well as other structural characteristics like cohesion, centrality, and hierarchy or the overall patterns of connections between actors.	NA	√

Scholars demonstrated that the centrality of a focal firm as well as the density of the supply network in which it is embedded are the likely determinants of its adoption of sustainability practices, in that they affect the ease of communication and efficiency of information flow across a network (e.g. Vurro et al., 2009). First, as network connections are often conduits for diffusing information and knowledge about firms' sustainability practices, a central actor is well positioned to transfer the knowledge and, thus, facilitates the sharing of sustainability-related activities (Beckman et al., 2009). Focal firms with high centrality will use power and influence to encourage other actors, such as suppliers, to adopt social practices (Vurro et al., 2009). Additionally, previous research has associated the density of network connections with diffusion of environmental business practices (Tate et al., 2013). For instance, Frostenson and Prenkert (2015) demonstrated that the degree of network density influences the suppliers' sustainability practices (i.e. CSR engagement). Specifically, as density increases, the embedded actor receives increased monitoring from other actors; thus, suppliers' CSR engagement within the highly connected supply networks is amplified. Furthermore, a network with high density will ensure or force the focal firms to be consistent and transparent to the responsible practices that they contend to (Vurro et al., 2009).

Previous research also highlighted the role of network complexity in the sustainability performance of embedded firms (e.g. Meinlschmidt et al., 2018; Wilhelm et al., 2016). Meinlschmidt et al. (2018) identified that a focal firm's structural supply network complexity (i.e. the overall degree of the horizontal complexity - the number of suppliers in each tier), vertical complexity (the numbers of tiers in a system), and spatial complexity (the dispersion of tiers among different countries and locations) and Choi & Hong (2002) determined the degree of perceived sustainability risk in terms of uncertainty of lower-tier suppliers' sustainability conduct. Particularly, high structural complexity may indicate buying firms' lack of sufficient knowledge of their lower tier suppliers and the need for greater transparency on lower-tier actors. Consistent with this, Wilhelm et al. (2016) demonstrated that the supply chain vertical and horizontal

complexity determines the buying firm's sustainability performance (i.e. extending sustainability management strategies to its sub-suppliers). The varying levels of horizontal complexity of lower tier suppliers lead to different sustainability management strategies, e.g. sub-suppliers sustainability tasks delegation, governance structures change (i.e. working with third-parties).

In a last description of how the literature has attempted to explain sustainability performance of firms within supply networks, a number of scholars have drawn on the notion of the structural hole, which refers to the lack of linkages among firms and their simultaneous indirect connections such as lower-tier suppliers (Burt, 2002). For instance, Saunders et al. (2017) employed the concept of brokerage exchange in advancing the view that actors serving as exchange brokers (e.g. as a government, coalition, industry action group, etc.) within a supply network can help bridge the network's existing structural holes by way of enabling a focal firm's access to the resources and knowledge of the sustainability initiatives from members of other network clusters. Furthermore, early network literatures (Burt, 2002; Grannovetter, 1973) suggested that the structural holes are often bridged by the creation of weak ties (also known as bridging ties). A bridging tie links connects two nodes that are not directly connected to each other through their respective contacts, which by definition is a weak tie (Michelfelder & Kratzer, 2013). Drawing on the concept of a weak tie, Roscoe et al. (2016) further indicated that focal firms should build weak ties with their suppliers that bridge structural holes in supply networks. Bridging weak ties may help facilitate greater information access and enable firms to tap into the resource base of an entirely different network. This also indicated that focal firms might receive benefits from new knowledge and opportunities for finding innovations to enhance sustainability performance (i.e. discover radical eco-innovations under the conditions of technological uncertainty). Additionally, scholars from the fields of business and society has defined bridging organisations (i.e. the third ones who join) as those that extend ties among organisations from different domains. These bridging organisations are more experienced and efficient in the implementation of sustainability (Wilhelm et al., 2016). For instance, the third party, such as experienced NGO, could span a hole

to bridge the relevant resources for the poor suppliers and the buying firms regarding social sustainability practices (e.g. poverty alleviation). NGOs as actors possess higher bridging capability to bridge between the buying firm and sources for funding, and generally in establishing or strengthening ties between poor suppliers and buying firms (Rodríguez et al., 2016).

Drawing upon the notion of structural properties of the supply network, some scholars have implied that structural properties may help distribute the sustainability-related resources from impersonal configurations of linkages from supply network actors to actors and determine the extent and range of resources that are within reach (Moran, 2005). Therefore, I propose:

Proposition 3a. *The structural positions of firms within supply networks in terms of centrality and structural holes positively affect the supply chain sustainability performance at focal firm level.*

Proposition 3b. *The structural properties of networks in which firms are embedded in terms of density of ties and complexity positively affect the supply chain sustainability performance at focal firm level.*

2.5.3 The interactive effect of network structural properties and governance mechanisms on sustainability performance in supply chains

Whilst the literature has largely demonstrated the individual effect of network governance mechanisms and structural properties on managing sustainability performance in supply chains, recent research has steered investigation towards the interactive effect between the two as it relates to driving sustainability performance (see Table 2-9).

Table 2-9 Interactive effect of network structural properties and governance mechanisms on sustainability performance in supply chains

Moderator		Unit of analysis	Sustainability performance	
Network dimensions	Author: Definitions/ Measurements		Environmental dimension	Social dimension

1. Centralisation	Tachizawa and Wong, 2015:	Network	✓
2. Density	1. the extent to which		
3. Supply network complexity	the overall connectedness is organised around particular nodes in a network; it also refers to the degree to which authority or power of decision making is concentrated		
	2. number of total ties in a network relative to the number of potential ties		
	3. the product of the number of entities and the number of interactions within a system		

Tachizawa and Wong (2015) have provided a seminal illustration of this view by way of three lines of argument. First, the authors argue that *centrality* has a positive moderating effect on the relationship between formal governance mechanisms and environmental performance, whilst negatively moderates the effect on the relationship between informal governance mechanisms and environmental performance in the supply chains at network level. As an example, centralisation decreases the information asymmetry in supply network in terms of complying with formal procedures (Sarkis et al., 2011; Touboullic et al., 2018). In practice, centralisation improves the controllability of formal control mechanisms in relation to the implementation of green practices on product design to assure quality (Choi & Hong, 2002; Kim et al., 2011). Conversely, informal governance is typically associated with a loosely coupled process, while centralised authority requires a tight coupled process to make decisions more quickly and effectively. Also, as trust is crucial for the effectiveness of informal green supply chain management, the centralisation of activities associated with mediated forms of power may change the sustainable behaviour of the target due to the control of reinforcement. Therefore, it negatively affects the trust within the supply network in relation to environmental performance and moderates their relationships.

Second, the authors have suggested that network density operates counter to centrality – that is, negatively moderating the effect between formal governance mechanisms and environmental performance, whilst positively moderating the effect of informal governance mechanisms on environmental performance (Tachizawa & Wong, 2015). This effect is dependent on the type of tie, which manifests as either hard tie (in the form of material and money) or soft tie (in the form of information and values). Instances of hard ties and soft ties share in their particular negatively moderating influence: hard ties increase the coordination costs of the lead firm, whilst soft ties allow suppliers to interchange information and, in doing so, provide means to avoid environmental problems during audits and act opportunistically (Tachizawa & Wong, 2015). Conversely, a highly dense supply network could reduce transaction costs in informal supply networks and enhance collaboration. Moreover, soft ties appear to be more crucial to informal governance mechanisms in supply networks than hard ties. Actors have a tendency to form relationships where they share similar attributes (e.g. perception and values towards sustainability practices) leading to a closer connection along the different tiers.

In a last significant observation, Tachizawa and Wong (2015) have opined that supply network complexity appears to negatively moderate the effect of relationships between formal governance mechanisms and environmental performance, while positively moderating the effect of relationships between informal governance mechanisms and environmental performance at the network level. Formal governance mechanisms are often associated with the tightly coupled supply network, the formal process or outcome may be influenced unexpectedly due to the complexity. For instance, Wilhelm et al. (2016) pointed out that high supply chain complexity leads to particular challenges in managing sustainability implementation, even the unambiguous certification is introduced. Additionally, supply network complexity also increases the burden of network management. For instance, firms may be aware of sustainability misconduct due to the high complexity in supply network and, therefore, devotes more time, resources, and money in sustainability management (Hofmann et al., 2014). In contrast, they argued that the number and diversity of network actors may

facilitate information sharing and motivate suppliers to identify their own problems and compare their sustainability performance to other actors. For instance, informal governance mechanisms entitle the network actors to more self-organisation and decentralised coordination. Hence, I propose:

Proposition 4. *Supply network structural properties, such as density, centrality, and complexity, are likely to moderate the effect between network governance mechanisms and the sustainability performance at the network level.*

2.6 Directions for future research

Through thematic analysis of the existing literatures, two main avenues for future research have been identified.

2.6.1 The role of network properties in supply chain sustainability

Current bodies of scholarly works have already acknowledged the role of supply network structural properties regarding the sustainability performance of embedded firms within their supply chains, however, there is a lack of empirical grounding in the existing studies; the structural properties emerging in supply networks have been extensively observed on a large scale. Nonetheless, there are no studies that empirically investigate the structural properties of a large-scale and real-world supply network regarding the sustainability performance of embedded firms and network. In particular, extant research examining the connectivity patterns in supply chains have mainly put focus on the application of theoretical network metrics, such as centrality or density; however, little attention has been given to interpreting these metrics or development of novel ones in the specific context of supply chain sustainability. Future studies are thus required to unravel and examine the interfirm connectivity patterns of a real-world large-scale supply network to develop means to explicate the impacts on both the sustainability of embedded firms (actor-level analysis) and the whole network (network-level analysis).

Current studies that examine supply network connectivity patterns adopt a structuralist view where, in the evaluation of sustainability outcomes, dyad-level contingencies are largely ignored. While the prior work largely assumes that

network members are connected through equal and balanced ties, a more granular comprehension of the role of network connectivity patterns requires re-examination so as to accommodate the dyad-level analysis. In particular, the structural attributes need to be examined in light of relational strength and quality.

2.6.2 Network level of sustainability performance

Most studies examining the role of networks in the context of sustainability performance have focused on the embedded firm and, generally, studies considering the sustainability measurements beyond embedded firm level remain sparse. While expanding the unit of analysis from firms to entire supply networks requires new constructs, few studies exist that have conceptualised and operationalised supply chain sustainability at the network level. Furthermore, as most lower-tier suppliers use the sustainability measurements that are implemented by the focal firm, few studies have discussed the importance of assessing and measuring sustainability performance from other network actors' perspectives (i.e. consumers, non-business actors). Sustainability measurements in the form of a broader unit of analysis (i.e. through use of a network level lens) offers rich opportunity for researchers to examine how to incorporate sustainability at the network level and may suggest a conceptually novel way to engage network actors in multi-tier supply chains in making commitments to sustainability directives. Particularly, the substances of such scholarship would allow companies to reflect how they measure and evaluate sustainability performance at the network level and offer a practical guide towards operationalising appropriate measurements.

In addition, by examining the network determinants of the sustainability performance in supply chains, the focus has been primarily on one sustainability dimension. Specifically, existing studies have not distinguished well between the environmental sustainability and social sustainability. For instance, it is rarely observed the degree that influences social and environmental sustainability performance with different network determinants within the supply networks. Considering the nature of sustainability measurement items across different sustainability dimensions, it is thus imperative to call for more understanding on

how social and environmental performance are individually and collectively affected by network determinants.

2.7 Conclusions

Over the past few years, in investigating collaboration for sustainability, the areas of operations and supply chain management have moved from a basic buyer-supplier dyad to focussing on the interaction of multiples actors. This paper has attempted to illustrate the role of networks in sustainability performance in supply chains by integrating and assessing the extant literature and adopting a network perspective in explaining sustainability performance. In particular, I have identified network relational (i.e. network-level collaboration and network governance mechanisms) and structural properties that affect the sustainability performance in supply chains at two levels of firm and network.

Given the network perspective proposed by Grannovetter (1973) and Burt (2002), this study analyses the different roles of network regarding supply chain sustainability. This study examines the existing literatures focusing on the relationships that occur among three actors and beyond in the sustainable SCM. Besides, this study also identified the various network structural and relational properties in implementing and diffusing supply chain sustainability. In line with this, this study categorised these network properties into two different groups in which they share the same role in terms of sustainability performance. As analysed, the network can act as determinant and moderator in relation to sustainability performance. This provided the insights of current status of the art in the role of networks in managing sustainability in supply chains. In addition, this study also carefully differentiates the sustainability performance of different units of analysis, i.e. focal firm and supply network levels. In accordance with this, this study also develops several theoretical propositions for understanding supply chain sustainability that goes beyond the dyadic relationship, contributing to the future studies on the area.

From the managerial perspective, this study synthesised the views in the area and offers several practical implications to practitioners of embedded firms when they adopt a network lens in terms of whole supply networks in advancing

sustainability performance. For instance, this study guided firms to consider the structural investigation of embedded firms on implementation of supply chain sustainability in that patterns and connectivity of the embedded focal firm affected sustainability performance differently. At the same time, this study also suggest that practitioners should invest in developing and using plural forms of governance mechanisms, i.e. formal and informal mechanisms together to govern through their supply chains in addressing social and environmental sustainability issues. Furthermore, the study also unravelled that the importance of considering the perspectives of sub-suppliers. It is found that management of lower or indirect suppliers is often neglected. Especially, in terms of achieving social sustainability, their voices must be included. Their perceptions and values towards sustainability will greatly affect the implementation of sustainability and their understanding of green or SSCM and also influence the way they behave in the supply chain process, e.g. sourcing ethically in terms of environmental standards, enhancing employee welfare fairly, etc. Therefore, this study suggests that firms should take into consideration better training the sustainable behaviours, framing, and delegation of sustainability to lower-tier partners.

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3 The role of supply network structural properties on firm sustainability: an empirical investigation

Abstract

The researcher's study aims to empirically examine how the structural properties of the supply networks (i.e. the complex, unique and often-invisible interfirm connectivity patterns) in which firms are embedded influence their sustainability performance. To test the hypotheses, I used a supply network dataset consisting of 18,943 firms and 103,632 contractual links from the automotive industry. The sustainability performance data in terms of environmental and social aspects were obtained, using Thomson Reuters Eikon database, for 273 firms with publicly reported available data. The results demonstrate a positive relationship between the interconnectedness of a firm's supply network and its sustainability performance. Consistent with previous research, the study also establishes the importance of firms' sustainability commitment in determining sustainability performance. However, findings revealed that this relationship is contingent on firms' centrality in the supply network. By distinguishing between upstream and downstream ties, the study shows that while firms' in-degree centrality weakens the relationship between their commitment to sustainability and extent of sustainability performance, out-degree centrality strengthens this association. This study extends the emerging discussion on the criticality of broader supply networks in driving sustainability by investigating the role of interfirm connectivity patterns of a real-world large-scale supply network. Also, these findings add to the literature regarding the role of sustainability commitment in developing firms' sustainability performance by incorporating structural contingency factors not considered in the prior literature.

Keywords: Sustainability; Sustainability commitment; Supply network structure; Social network analysis

3.1 Introduction

Firms are facing increased pressure from various stakeholders to incorporate social and environmental considerations into their strategies and operations (Wang et al., 2016). Yet, the successful realisation and achievement of social and environmental objectives extend beyond the boundaries of one single firm. Firms more and more engage in relationships with various upstream and downstream actors across their supply chains to achieve these sustainability goals (Chen et al., 2017; Miemczyk et al., 2016). Scholars have conceptualised and investigated various practices firms have adopted and implemented throughout their supply chains to achieve sustainability (e.g. communication, monitoring, and assessment of sustainability targets and collaboration to develop sustainability capabilities and introduce sustainable innovations (Gimenez et al., 2012; Tachizawa & Wong, 2014; Aytekin et al., 2023).

Even though the existing literature was initially dominated by studies investigating sustainable supply chain management practices that the firm implements regarding its first-tier suppliers (e.g. Cheng et al., 2008; Chkanikova, 2016), a growing body of work recently has revealed the cruciality of a broader supply networks, including lower-tier suppliers, in achieving sustainability (e.g. Sauer & Seuring, 2018; Santos et al., 2023; Tachizawa & Wong, 2014). Specifically, most recent studies have revealed the importance of complex, unique and often invisible connectivity patterns (i.e. the network structure) that surround firms in achieving their sustainability goals (e.g. Alinaghian et al., 2021; McLoughlin & Meehan, 2021; Saunders et al., 2019). While scholars have started to discuss the role of supply network structural properties in relation to sustainability performance of the embedded firms, there is a lack of empirical grounding in the literature. The structural properties of supply networks that are now developing are largely observable on a large scale (Brintrup & Ledwoch, 2018). Nonetheless, an empirical investigation of the structural properties of large-scale real-world supply networks in relation to the sustainability performance of the embedded firms has yet to be attempted. Thus, this study aims to empirically examine how

the structural properties of the supply networks in which firms are embedded influence their sustainability performance.

In this article, I posit that the interconnectedness of the supply network in which a firm is embedded (i.e. the proportion of all possible connections present among supply network partners of a firm relative to the total number possible) (Bellamy et al., 2014; Kim et al., 2011), can be a key enabler of its sustainability performance. Research suggests that a highly interconnected supply network, in which most members connect with one another, facilitates knowledge and information flow (Bellamy et al., 2020; Dyer, 1996; Dyer & Hatch, 2004) and, thus, promotes collaboration amongst network members to develop sustainability capabilities (Koh et al., 2012; Miemczyk et al., 2012; Villena & Gioia, 2020). In addition, previous research has established the importance of highly connected supply networks in enforcing shared and firmly held sustainability values and norms among members (Fontana & Egels-Zandén, 2018; Lu et al., 2018). This study therefore begun to ask the first research question: i.e. whether the interconnectedness of the firm's supply network is related to the firm's greater sustainability performance.

The study also examines the moderating role of a firm's supply network structural position in sustainability performance. Although previous studies have outlined the importance of firms' internal efforts and demonstrated that firms with higher commitment to sustainability (also referred to as sustainability orientation) enjoy stronger sustainability performance (Carrillo-Higueras et al., 2018; Chen & Chen, 2019; Cheng, 2020), which is consistent with recent studies (e.g. Bellamy et al., 2020). I argue that this relationship is contingent on a firm's position relative to its supply network. Previous research has argued that firms' degree of centrality (i.e. a firm's number of direct connections, Borgatti & Li, 2009) can play a role in determining the firm's influence over its connections' adoption of sustainability initiatives (Beckman et al., 2009; Vurro et al., 2009) and accessing sustainability-related information (Villena & Gioia, 2020). However, the existing literature has not investigated how a firm's central position in supply networks interplays with its internal sustainability efforts to shape the sustainability performance.

Therefore, the study's second research question seeks to ask how a firm's central position in its supply network moderates the sustainability commitment-sustainability performance relationship.

To test the hypotheses, I used a supply network dataset consisting of 18,943 firms and 103,632 contractual links between them from the automotive industry. Furthermore, this study adopted the open-source software Gephi to visualise and calculate firm-level network structural metrics. The sustainability performance data in terms of both environmental and social aspects were obtained, using Thomson Reuters Eikon database, for 304 firms with publicly reported available data (of which 273 were included in the main model due to missing data on control variables).

This study also adds several contributions to the existing literature on supply chain sustainability and supply network structure. First, the study extends the emerging discussion on the criticality of broader supply networks in driving sustainability by investigating the role of interfirm connectivity patterns of a real-world large-scale supply network. Specifically, the study demonstrates a positive relationship between the interconnectedness of a firm's supply network and its sustainability performance. Second, the study determines the moderating role of firms' supply network structural properties in the relationship between their sustainability efforts and sustainability performance. In particular, these results add to the literature regarding the role of sustainability commitment in shaping firms' sustainability performance by incorporating an additional contingency factor that has not been discussed in the previous studies. By distinguishing between firms' upstream and downstream ties, the study shows that whereas firms' in-degree centrality weakens the relationship between their commitment to sustainability and the extent of sustainability performance, out-degree centrality strengthens this association.

The remainder of the chapter is structured as follows. First, I develop theory linking the structural properties of firms' supply networks, their commitment to sustainability, and sustainability performance. Second, the data, variables, and measures are described. Third, the main results are presented including those of

various other analyses and robustness checks. Finally, the findings are presented together with their implications before concluding with a discussion of limitations and areas of future research.

3.2 Theoretical background and hypothesis development

Previous research has investigated sustainability performance of firms in relation to their environmental and social impacts (Centobelli et al., 2022; Miemczyk et al., 2012; Pullman et al., 2009). The environmental dimension refers to the impacts of firms' activities on the environmental resources such as waste, emissions, consumption of toxic materials, and frequency of environmental accidents (Tachizawa & Wong, 2015), whereas the social dimension emphasises the impacts on the social resources that are involved in firms' value creating activities in terms of health and safety, human rights, community, and diversity (Zorzini et al., 2015). The existing studies have pointed out several internal factors that are considered to be the key determinants of firms' sustainability performance such as board-level commitment to sustainability (Burke et al., 2019), firm-specific resources and capabilities (Paulraj, 2011), and internal self-regulations such as statements of codes of conduct (Mijatovic & Stokic, 2010). With 90% of firms' environmental impact often coming from their extended supply networks (Bové & Swartz, 2016), firms are increasingly required to invest and engage in relationships with various network members in order to attain their sustainability goals. Current studies have suggested that firms engage in collaborative processes with various actors across their supply chains to develop sustainability capabilities (Arora et al., 2020) or introduce sustainable innovations (Beske & Seuring, 2014). Firms also establish codes of conduct or use monitoring processes, such as audits, to diffuse sustainability targets and evaluate the sustainability performance of their network members (McLoughlin & Meehan, 2021; Tachizawa & Wong, 2014).

In recent years, a growing body of studies have started to examine the role of the broader network of relationships in firms embedded in their supply chains in achieving the sustainability goals. In particular, prior studies have established the importance of management, orchestration and governance of firms' multi-tier

supply chains (Awaysheh & Klassen, 2010; Gong et al., 2018; Meinlschmidt et al., 2018; Sauer & Seuring, 2018; Tachizawa & Wong, 2014). As an instance, to achieve its sustainability goals, a firm may bypass the first-tier suppliers and build direct contract with lower-tier suppliers to directly monitor or collaborate with a second-tier supplier (Tachizawa & Wong, 2014). The study extends this line of research by investigating the structural properties of supply network in which firms are embedded and their role in achieving sustainability.

Adopting a SNA perspective, supply chain scholars have recently examined a variety of characteristics of the supply network connectivity patterns to draw implications about the network as a whole or about firms belonging to it (Han et al., 2020; Kim et al., 2011; Yan et al., 2015). From a SNA perspective, a network consists of nodes representing the network members and the linkages or ties that connect those (Borgatti & Li, 2009). In the context of the supply network, nodes consist of suppliers, manufacturers, service providers, and customers, who are linked together due to deliveries and receipts of materials, components, and modules or via supply contracts (Choi & Hong, 2002; Kim et al., 2011). Scholars suggest that the relative position of supply chain members within the overall patterns of network connectivity influences their behaviour and performance (e.g. Kim et al., 2011). As an instance, previous literature has demonstrated the role of various supply network structural properties in innovation (e.g. Bellamy et al., 2014) or effectiveness of risk management and resilience (e.g. Kim et al., 2015; Ledwoch et al., 2018) of embedded firms. Furthermore, several studies in recent years have also started to highlight the role of supply network structural properties in explaining and investigating firms' sustainability performance (Alinaghian et al., 2021). In particular, recent literature has suggested both the direct effect and moderating effect of supply network structural properties on the sustainability performance of the embedded firms (e.g. Bellamy et al., 2020).

This study examines two network structural properties that act as important determinants of firms' sustainability performance: (1) the level of interconnectedness in firms' local supply network and (2) the level of firms' degree centrality. First, it is posited that the interconnectedness of the supply

network in which a firm is embedded can be a key enabler of a firm's sustainability performance. Additionally, I propose that a firm's degree centrality has a contingent effect on the relationship between the firm's internal efforts in driving sustainability and its sustainability performance. The contingency role of firms' structural properties on the effectiveness of firms' administrative environmental innovations in their environmental disclosure has recently been documented in the literature (Bellamy et al., 2020). It is also argued that a firm's degree centrality can facilitate or impede its internal sustainability efforts in achieving sustainability goals. I build on the concept of sustainability commitment defined as "the extent to which an organisation engages with environmental or social initiatives in order to reduce negative impacts" (Luzzini et al., 2015, p. 53) to represent a firm's internal efforts towards sustainability. The hypothesised research model is presented in Figure 3-1.

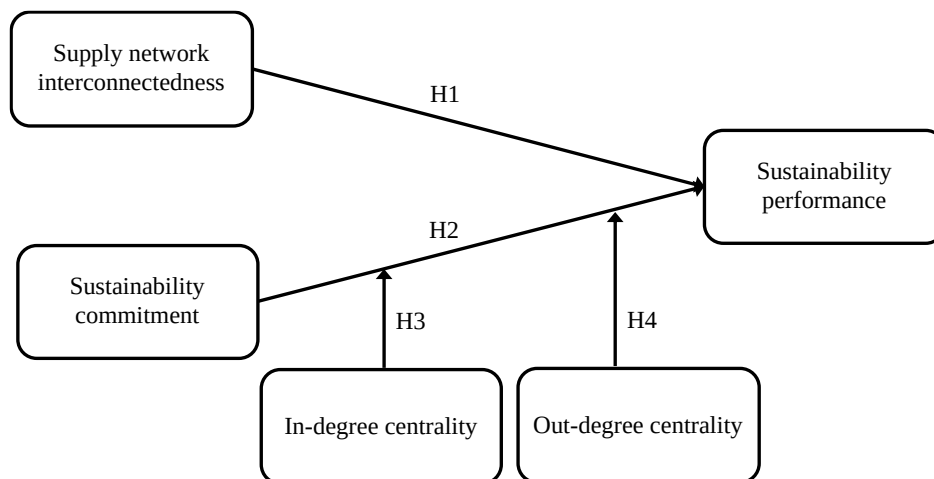


Figure 3-1 Hypothesised research model

3.2.1 Supply network interconnectedness and sustainability performance

Supply network interconnectedness is defined as "the degree to which supply network partners of a focal firm are connected to each other, and thus share direct links amongst themselves" (Bellamy et al., 2014, p. 360). Also referred to as network density, interconnectedness represents the level of presence or absence of network ties between actors (Tong et al., 2018) and is operationalised through the ratio of the number of ties between actors to the total possible number of ties

in the network (Borgatti & Halgin, 2011). Figure 3-2 displays the different levels of supply network interconnectedness that a firm could have in its supply network.

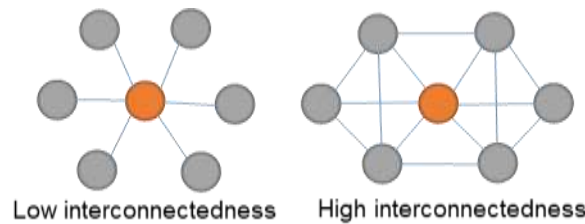


Figure 3-2 Illustration of levels of supply network interconnectedness

I posit that the interconnectedness of the firm's supply network positively influences its sustainability performance regarding the following reasons. First of all, suppliers embedded in highly interconnected supply networks are always responsible for the others' actions due to the high level of interdependency (Chen, 2018). Highly connected supply networks tend to enforce shared and firmly held norms among their network members (Wu & Pullman, 2015). In these networks, suppliers would be encouraged to engage in collective behaviour towards sustainability because of the normative pressure and distributed power (Fontana & Egels-Zandén, 2018; Nath et al., 2019). Such pressure and power would also encourage embedded suppliers to make investments in radical changes and support the adoption of sustainability initiatives (Sayed et al., 2017).

Second, the extant literature has established the importance of interconnectedness of partners in a supply network to information flows within the network (Bellamy et al., 2020). Scholars have demonstrated that as network partners of a firm become more connected, information flows (Liang & Fu, 2019; Schilling & Phelps, 2007) and knowledge spillover (Harrigan et al., 2012) are facilitated in the supply networks. In examining the supply network context, previous studies suggest that a high level of interconnectedness among upstream and downstream partners of a firm facilitates efficient knowledge sharing (Galaskiewicz, 2011; Potter & Wilhelm, 2020). Although network interconnectedness is associated with information redundancy (Burt, 2004), scholars have argued that high level of interconnectedness would be beneficial for the diffusion of information (Liang & Fu, 2019) and increases the information

contagion (Harrigan et al., 2012). Indeed, such repeated exposure to information allows the embedded suppliers to validate information and build confidence to invest in and adopt new practices (Chauhan et al., 2021; Jenssen & Greve, 2002; Reagans & McEvily, 2003). Previous studies have established the role of information sharing in attaining firms' sustainability performance (Busse et al., 2017; Khan et al., 2016). I conclude that high level of interconnectedness also eases the communication of sustainability-related information in supply networks, which then provides the embedded firms with greater levels of sustainable inputs, hence enhancing their sustainability performance. Accordingly, I posit the following:

H1: The interconnectedness of a firm's supply network is positively associated with its sustainability performance.

3.2.2 Sustainability commitment and sustainability performance

The notion of sustainability commitment (also referred to as sustainability orientation) characterises the extent to which a firm involves in environmental and social sustainability initiatives to diminish negative impacts (Bansal & Roth, 2000; Luzzini et al., 2015) and shows its proactive and continuous efforts in addressing social and environmental challenges (Chen & Chen, 2019). Sustainability commitment places sustainability as an integral part of firms' overall management philosophy, strategic planning, strategic product decisions, and competitiveness (Foerstl et al., 2015; Jansson et al., 2017).

Previous studies have also investigated the impacts of sustainability commitment on firms' sustainability performance. For instance, Bhatia & Jakhar (2021) and Bowen et al. (2001) provided support and revealed that firms' environmental proactivity has a positive association with the implementation of green supply initiatives. Researchers have further established the importance of commitment to environmental sustainability and its contributing role in implementing the sustainability effectively and, thus, firms' performance (Carrillo-Higueras et al., 2018; Dias et al., 2021). Similarly, scholars have shown that firms with commitment to social sustainability often adopt a value-oriented business logic that leads to new sustainable value co-creation opportunities (Dahlin et al., 2020).

In general, research demonstrates that firms with higher commitment to sustainability enjoy stronger sustainability performance (Chen & Chen, 2019; Cheng, 2020). Therefore, consistent with the existing literature, I hypothesise:

H2: The sustainability commitment of a firm is positively associated with its sustainability performance.

3.2.3 Degree centrality, sustainability commitment and sustainability performance

In a directed supply network, degree centrality refers to the number of ties a firm has with its upstream suppliers (in-degree) and downstream customers (out-degree) (Borgatti & Li, 2009; Kim et al., 2011). Degree centrality in supply networks reflects the degree of a firm's operational load (i.e. supply load and demand load) and, indeed, the point to which the firm has an influence in terms of impacting (or being impacted by) the operational decisions and strategic behaviour of other upstream and downstream connections, hence embodying the importance of firms (Kim et al., 2011). This study examines how a firm's in-degree and out-degree centrality (shown in figure 3-3) may enhance or weaken the influence of the firm's sustainability commitment on its sustainability performance. In fact, it is posited that the relationship between a firm's sustainability commitment and sustainability performance is also reliant on a firm's ability to manage supply chain relationships. I distinguish between upstream and downstream ties (Potter & Wilhelm, 2020) by separately investigating the contingent effect of in-degree centrality and out-degree centrality on firms' sustainability commitment-sustainability performance relationship.

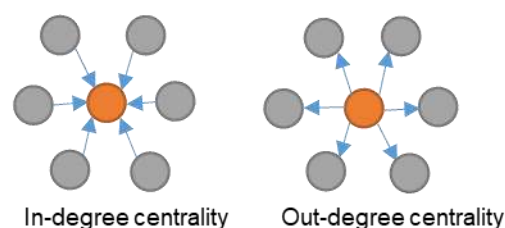


Figure 3-3 Illustration of a firm's in-degree centrality and out-degree centrality

Prior research has suggested that firms with many upstream ties would have the influence and power to inspire, incentivise or require their suppliers to adopt sustainability initiatives (Castka & Balzarova, 2008; Tachizawa & Wong, 2014). Additionally, firms embedded in a highly central upstream network position are best placed to facilitate the information flows resulting from the direct interactions with many network members (Arora & Brintrup, 2021). In particular, firms' central position in the upstream network enables them to easily set and diffuse sustainability targets and demand compliance from many suppliers (Castka & Balzarova, 2008; Villena & Gioia, 2020; Vurro et al., 2009). The literature suggests that firms only use their influence and facilitate sustainability-related information where they demonstrate strong commitment to sustainability (Luzzini et al., 2015; Pagell & Wu, 2009). Overall, these arguments suggest that firm's upstream central position strengthens the positive effects of its commitment to sustainability on its sustainability performance. Therefore, I hypothesise:

H3: The in-degree centrality of a firm positively moderates the relationship between its sustainability commitment and sustainability performance.

The literature further provides a conflicting prediction on the moderating role of firms' in-degree centrality in firms' sustainability commitment–sustainability performance relationship. Studies argue that firms' in-degree centrality is associated with higher operational burden (Kim et al., 2011). Specifically, firms occupying central positions in upstream networks are often tasked with organising and including different parts from various suppliers to conserve overall product or service integrity (Parker & Anderson, 2002). This issue becomes salient when these firms demonstrate strong commitment to sustainability. Central firms with strong commitment to sustainability tend to establish and diffuse sustainability targets across a wide network of suppliers and orchestrate extensive monitoring processes to evaluate network members' sustainability performance (Tachizawa & Wong, 2014). Additionally, these firms tend to have a wide range of sustainability initiatives that will require heavy engagements with several suppliers (Arora et al., 2020; Beske & Seuring, 2014); these firms experience higher sustainability load that can negatively influence their

sustainability performance (Vachon & Klassen, 2006). Thus, an alternative hypothesis to H3 has also been developed:

H3-competing: The in-degree centrality of a firm negatively moderates the relationship between its sustainability commitment and sustainability performance.

Previous studies suggest that firms having many downstream ties tend to be a common supplier to multiple downstream firms (Kim et al., 2011). For firms with strong commitment to sustainability, out-degree centrality positions create opportunity to access sustainability-related information from a high number of customers and, thus, provide them with greater exposure to customers' sustainability expectations and practices (Vurro et al., 2009). Furthermore, these firms would have the opportunity to aggregate their customers' environmental and social requirements and demands and, thus, benefit from an economy of scale, which allows them to be more effective and efficient in achieving their sustainability goals. In particular, as the accountability in sustainability often lies with downstream customers (Hartmann & Moeller, 2014; Schmidt et al., 2017) who need to collect and integrate sustainability-related information from their upstream suppliers, unlike in-degree centrality, firms' central positions in their downstream network does not lead to higher operational burden. Therefore, I posit the following:

H4: The out-degree centrality of a firm positively moderates the relationship between its sustainability commitment and sustainability performance.

3.3 Methodology

3.3.1 Research setting and data collection

A database was created using the following data sources: MarkLines Automotive Information platform, Thomson Reuters Eikon, and Bloomberg. The progressive dis-verticalisation of the automotive industry has led firms to rely on a highly fragmented network of partners to deliver products and services (Christensen, 2011; Sturgeon & Memedovic, 2010). At the same time, the industry environment has increasingly pressured firms to continually minimise the negative impacts on

environment and society (Hartmann & Moeller, 2014; Villena & Gioia, 2020). Such a highly fragmented setting, in which firms' realisation and achievement of sustainability goals depend on networks of relationships in which they are embedded, provides an appropriate empirical research setting to investigate the role of supply network connectivity patterns in relation to firm's sustainability performance.

Additionally, the supply network data were retrieved from the MarkLines database in 2014. First, data on customers and suppliers of firms that advertise themselves on the database were downloaded. The customer and supplier data were used to determine connections between firms. Every firm was assigned a unique code. This allowed further identification of interconnections that existed among firms' upstream suppliers or downstream customers. The process resulted in a supply network consisting of 18,943 firms and 103,632 links between them.

I used Thomson Reuters Eikon database to obtain the sustainability performance data. To enhance and replace the ASSET4 ratings, Thomson Reuters ESG Scores were crafted to measure a firm's sustainability performance, clearly and factually, across the ten main indicators on the basis of data that have been disclosed in the public domain (Thomson Reuters, 2017). The availability of sustainability performance data was checked for the entire network of 18,943 firms, where ultimately a sample of 304 firms was identified. The sustainability data were collected from the year 2017, creating a 3-year time lag in the dependent variable. Consistent with the existing literature, time lagged sustainability performance data were used to better reflect the causal impact of the proposed determinants and address the endogeneity issue (Gualandris et al., 2021; Rajesh, 2020). Previous studies suggest that a firm's sustainability performance of the present year is influenced by the resources and/or initiatives from the preceding years (Drempetic et al., 2020).

In addition, a newly accessible data source, i.e. the Bloomberg SPLC Function, was adopted to collect data on control variables. The SPLC function maps firms' suppliers and buyers by snapshotting the most recent money flows between these firms on both a buyer (revenue) and supplier (cost) basis (Kim & Davis,

2016). In line with the time period of independent variables, the control variables data were collected from the year 2014. Data on the control variables were collected using the sample size of 304 firms for which the sustainability performance data were available. After checking the availability of data on these control variables in the SPLC function, a sample of 273 firms was included in the main model.

3.3.2 Dependent variable

Sustainability performance. The Thomson Reuters ESG scores were used as an indicator of the firm's sustainability performance (Rajesh, 2020). Thomson Reuters ESG scores provide a framework for the evaluation of sustainability performance of firms on a 10 main indicators and over 400 firm-level measures basis. The scores go beyond the widely applied ratings that merely focus on a firm's reporting and disclosure of sustainability (e.g. Bloomberg ESG data, Bellamy et al., 2020; Gualandris et al., 2021) by providing a transparent and objective measure of a firm's sustainability performance. Thomson Reuters ESG scores enhanced and replaced the extant ASSET4 Equal Weighted Ratings. These ESG scores (scores range is shown in Table 3-1) reflect a firm's ESG framework strategically, as well as representing a data-driven assessment of their ESG performances. This study collected scores on environmental (i.e. emission, resource use, environmental innovation) and social indicators (i.e. workforce, human rights, community and product responsibility). This allowed capturing a firm's sustainability performance across a range of domains. These indicators have been widely used by previous studies to investigate environmental or social dimension of sustainability performance both individually (e.g. Dixon-Fowler et al., 2017) and jointly (Shafiq et al., 2017). In terms of this, the description of the scores and variables are presented in the following Table 3-1 and 3-2.

Table 3-1 Description of scores (Source: Refinitiv, 2017)

Range	Percentile	Description
Scores between 0 to 25	1 st Quartile	This score range suggests inadequate relative ESG performance and insufficient level of transparency in the public disclosure of material ESG data.
Score between 25 to 50	2 nd Quartile	This score range suggests satisfactory relative ESG performance and moderate degree of transparency in the public disclosure of material ESG data.
Scores between 50 to 75	3 rd Quartile	This score range suggests good relative ESG performance and above average degree of transparency in the public disclosure of material ESG data.
Scores between 75 to 100	4 th Quartile	This score range suggests excellent relative ESG performance and high degree of transparency in the public disclosure of material ESG data.

Table 3-2 Description of variables

Construct	Variable	Variable Type	Year	Measure	Data sources
Sustainability performance	Environment + Social	Dependent	2017	Environmental scores (emission score, resource use scores, environmental innovation scores) Social scores (workforce scores, human rights scores, community scores, product responsibility scores)	Thomson Reuters Eikon
Firm size	Natural log of sales	Control	2014	Firm size=ln(Sales)	Thomson Reuters Eikon
Firm age	Number of years since the firm was established	Control	N/A	Age	Thomson Reuters Eikon
Firm sales growth	Sales growth	Control	2014	The ratio of the current year's total revenues to the prior year's total revenues minus one	Thomson Reuters Eikon
Supplier concentration	Supplier concentration	Control	2014	The percentage of a focal company's cost of goods sold that is spent on its five main suppliers	Bloomberg
Firm power over direct suppliers	Firm power over direct suppliers	Control	2014	Inventory turnover (cost of goods sold divided by the average inventory)	Thomson Reuters Eikon
Sustainability commitment	CSR strategy scores	Independent	2017	CSR scores	Thomson Reuters Eikon
Supply Network Interconnectedness	Local clustering coefficient	Independent	2014	Local clustering coefficient (i)=(2n _i)/(K _i (K _i -1))	MarkLines
Degree centrality	Degree centrality	Independent	2014	$C_D(n_i) = \sum_j x_{ij} = \sum_j x_{ji}$	MarkLines

3.3.3 Independent variables

Supply network Interconnectedness: I captured supply network interconnectedness as the network measure of the local clustering co-efficient (also known as node-level clustering coefficient), reflecting the extent to which a firm's supply network partners are connected to each other (Borgatti & Halgin, 2011); and thus the extent to which a firm's network partners form a cluster within the supply network (Potter & Wilhelm, 2020). Following Wasserman and Faust (1994), I calculated the local clustering coefficient for a focal firm i as:

Equation 3—1

$$\text{Local clustering coefficient } (i) = \frac{2n_i}{K_i(K_i - 1)} \quad (3-1)$$

where n_i denotes the number of links connecting the K_i neighbours of the focal firm i . Similar to Basole (2016) and Potter and Wilhelm (2020), I used Gephi 9.2 network software to calculate the measure of the clustering co-efficient.

Sustainability commitment: A firm's sustainability commitment – the degree to which firms engage with environmental and social sustainability initiatives to diminish the negative impacts – is an important factor affecting a firm's sustainability performance (Luzzini et al., 2015). Scholars argue that the strategic integration of sustainability in firms' core processes implies the communication between a firm and its stakeholders (e.g. Ballou et al., 2012; Nielsen & Thomsen, 2007). Previous research suggests that different sustainability reports that firms use to communicate their socially responsible behaviour indicates their level of commitment to sustainability (Fernandez-Feijoo et al., 2014). This study relied on disclosure practices that firms adopt to communicate their sustainability practices and behaviours as a proxy to assess their level of commitment to sustainability. Thus, I used the CSR Strategy score – a company's practice to communicate the integration of the economic (financial), social, and environmental dimensions into

its daily decision-making processes – reported in the Thomson Reuters Eikon database to measure sustainability commitment.

3.3.4 Moderating variables

In-degree centrality and Out-degree centrality: Similar to Brintrup et al. (2016), the total number of upstream ties and downstream ties were recorded for the firms identified in the MarkLines database. I developed the firm in-degree centrality variable measuring the total number of suppliers from which each firm sources materials, components, parts, and modules across the supply chain (Kim et al., 2011; Potter & Wilhelm, 2020). I further created the firm out-degree centrality variable measuring the total number of customers in the supply network to which each firm sells its products (Kim et al., 2011; Potter & Wilhelm, 2020). The in-degree centrality specifies the number of direct ties that flow to a firm from its suppliers, whereas the out-degree centrality indicates the number of direct ties that flow from the firm to its customers (Borgatti & Li, 2009; Potter & Wilhelm, 2020). I adapted the approach from the Brintrup et al. (2016) and Potter and Wilhelm (2020)'s research, and thus a firm in-degree centrality and out-degree centrality are outlined as:

Equation 3—2

$$C_D(n_i)^{in} = \sum_j x_{ij} \quad (3-2)$$

Equation 3—3

$$C_D(n_i)^{out} = \sum_j x_{ij} \quad (3-3)$$

where x_{ij} represents the binary variable equal to 1 if there exists a connection between n_i and n_j but equal to 0 otherwise (Freeman, 1979).

3.3.5 Control variables

Some control variables have been considered that may be related to the firm's extent of sustainability performance: firm size, firm age, sales growth, supplier concentration, and firm's power over suppliers. The control variables' data were obtained from two databases: the Thomson Reuters Eikon database and the Bloomberg database. The firm size, as captured by the natural log of total assets, may influence firm sustainability performance because a larger firm may have more possibility to get access to resources through their network of partners (Bellamy et al., 2014) and stronger capabilities to offer and report sustainability data (Drempetic et al., 2020). Additionally, larger firms tend to be under greater pressure to be transparent in terms of reporting the sustainability performance (Tamimi & Sebastianelli, 2017). This study also controlled for firm age, as measured by the number of years since the date of the firm was established to the current year of 2017. Older firms have had a longer time to adopt and fully implement various environmental certifications and voluntary and philanthropic activities than younger firms (Pistoni et al., 2016). Furthermore, sales growth, as measured by the ratio of the current year's total revenues to the prior year's total revenues minus one, may affect the sustainability performance because companies with more profitability tend to make more investments in sustainable practices (Chen et al., 2021).

Additionally, this study controlled for the firm's power over suppliers, as measured by the inventory turnover as a proxy of a firm's power over its direct suppliers (Kim & Davis 2016). A firm with more power over its suppliers has more control over the suppliers' decision-making and leverage to demand sustainability standards. The inventory turnover data were retrieved from the Eikon database.

Finally, the study controlled for supplier concentration. Adopting the measure used by Kim and Davis (2016), supplier concentration is measured by the percentage of a focal firm's cost of goods sold that is spent on its top five main suppliers after sorting the suppliers. Firms that have more complicated supply bases bear an increased operational load with regard to the monitoring and management of their supply chain network. Having complex supply chains can

hamper the firm's ability to investigate the entire supply chain network and, therefore, becomes less effective in managing its sustainability performance (Kim & Davis, 2016).

3.4 Empirical results

All analyses were run using STATA Version 16.1. The summary statistics (i.e. descriptive statistics, and the simple correlation of variables) were described in the Table 3-3.

Table 3-3 Descriptive statistics and correlation

	Variable	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10
1	Sustainability Performance	41.82671	14.9926	1									
2	Firm Size	8.577495	1.249086	0.5898	1								
				0									
3	Firm Age	77.56777	39.29924	0.2278	0.2319	1							
				0.0001	0.0001								
4	Firm Sales Growth	0.116102	0.418831	-0.073	-	-	1						
					0.0392	0.0856							
				0.2219	0.5066	0.1409							
5	Supplier Concentration	0.122576	0.159477	0.1354	0.1773	-0.1	0.0017	1					
				0.0225	0.0024	0.0821	0.9771						
6	Power over Supplier	6.89345	4.537566	-	0.1193	-0.022	0.0294	0.0881	1				
				0.1224									
				0.0417	0.0439	0.7085	0.6161	0.1325					
7	Supply Network Interconnectedness	0.106739	0.15912	0.0502	-	-	-	0.0868	-	1			
					0.0798	0.1167	0.0738		0.0793				
				0.3994	0.1738	0.0423	0.2037	0.1311	0.1756				
8	Sustainability Commitment	54.01198	28.92681	0.711	0.482	0.0611	-	0.0967	-	0.0351	1		
							0.0463		0.0413				

				0	0	0.3058	0.439	0.1039	0.4941	0.5554			
9	In-degree Centrality	0.00549	0.015161	0.1988	0.3929	0.0743	0.1234	0.0817	0.1368	- 0.2308	0.1429	1	
				0.0008	0	0.1971	0.0333	0.1553	0.0191	0	0.016		
10	Out-degree Centrality	0.000425	0.000713	-	-	0.0305	-	-	-0.002	-	-	-0.166	1
				0.0509	0.1339		0.0129	0.1466		0.1422	0.0681		
				0.3926	0.0221	0.5969	0.8242	0.0105	0.9721	0.0131	0.253	0.0037	

I also checked for multicollinearity. I ensured that the each predictor variable's VIF score was below 10, suggesting that multicollinearity issues were not in this given dataset (Neter et al., 1996). Thus, each of the VIF scores for the dataset satisfied the condition (the mean score is 3.94).

3.4.1 Main results

The empirical results were presented in the Table 3-4. In order to ensure the model's stability and the robustness of any significant effect against the inclusion of other effects, a sequential introduction of the effects was then employed in constructing models 1-4.

Table 3-4 Ordinary Least Square regression model-sustainability performance

VARIABLES	Model 1	Model 2	Model 3	Model 4
Controls				
Firm Size	6.893*** [0.000]	3.529*** [0.000]	3.443*** [0.000]	3.626*** [0.000]
Firm Age	1.513 [0.179]	2.676*** [0.004]	2.786*** [0.002]	2.583*** [0.005]
Firm Sales Growth	-1.887 [0.278]	-1.046 [0.459]	-1.158 [0.410]	-1.247 [0.371]
Supplier Concentration	3.489 [0.455]	3.756 [0.322]	3.439 [0.362]	2.924 [0.435]
Power over Supplier	-0.608*** [0.000]	-0.427*** [0.001]	-0.417*** [0.002]	-0.416*** [0.001]
Main Effects				
Supply Network Interconnectedness		6.811* [0.079]	7.431* [0.055]	7.740** [0.044]
Sustainability Commitment		0.278*** [0.000]	0.290*** [0.000]	0.259*** [0.000]
In-degree Centrality		44.875 [0.309]	304.987** [0.027]	290.719** [0.034]

Out-degree Centrality	522.801	618.222	-	-2.7e+03*
	[0.537]	[0.463]		[0.097]
Moderation Effects				
Sustainability Commitment*In-degree Centrality			-3.511**	-3.260*
			[0.047]	[0.063]
Sustainability Commitment*Out-degree Centrality				66.943**
				[0.018]
_cons	19.632***	13.225**	13.875***	-12.946**
	[0.001]	[0.013]	[0.009]	[0.014]
N	273	273	273	273
adj. R^2	0.369	0.596	0.6	0.607

p-values in brackets

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Model 1 is a base model including only the control variables and it is identified that some of which have significant results. Expressly, firm size is shown to affect the level of a firm's sustainability performance positively. Conversely, firm power over direct suppliers has a negative influence on sustainability performance, suggesting that the most questionable sustainability practices could happen among those distant suppliers. The main effects of supply network interconnectedness, sustainability commitment, and degree centrality are reported in the Model 2. The results indicate that the hypothesised supply network interconnectedness is positively and significantly related to sustainability performance and has received partial support ($p < 0.10$), thereby providing the support for H1. Furthermore, this model shows that the level of sustainability performance significantly enhances when the firm's sustainability commitment increases ($p < 0.001$), thereby providing strong support for H2. Models 3 and 4 incrementally include interactions that are in relation to H3 and H4. Model 4 represents the full model.

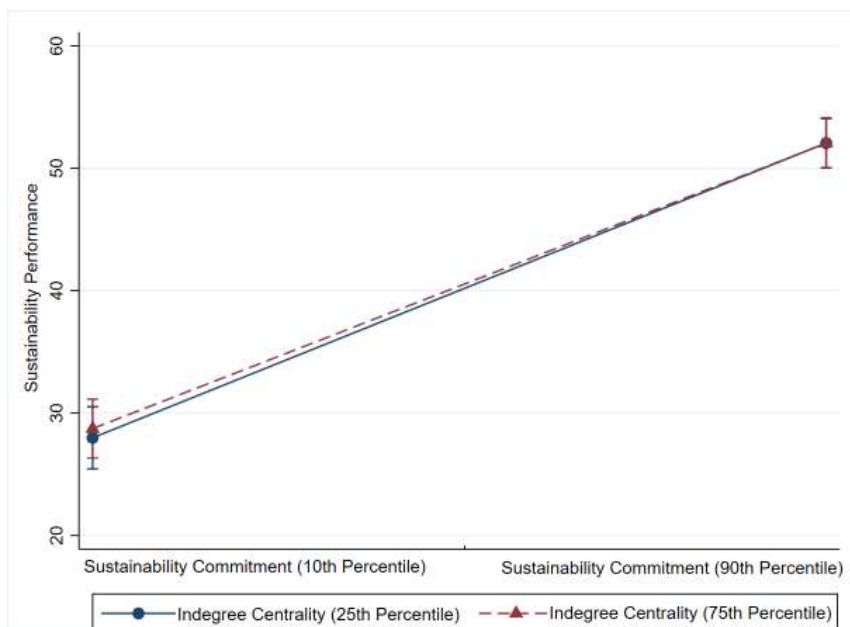
As hypothesised in the study, the coefficient representing the impact of supply network interconnectedness is positive (H1) (Shown in Table 3-3). Also, the association between a firm's sustainability commitment and sustainability performance (H2) remains positive throughout to the full model. Further, H3 and H4, which posited that degree centrality has a significant interaction effect on sustainability commitment, are supported ($p < 0.05$). The results also indicate that a firm's in-degree centrality negatively moderates the association between sustainability commitment and sustainability performance, thus showing at least partial support ($p < 0.1$) for H3-competing. Lastly, the results confirmed the significant positive moderating role of out-degree centrality ($p < 0.05$). Model 4 presents all the results that are an improvement over the previous models.

3.4.2 Moderating effects

Although H3 suggests the positive moderating of in-degree centrality, in line with H3-competing, firms' in-degree centrality weakens the relationship between sustainability commitment and sustainability performance. Interaction plots were used for a more detailed examination of the moderating effects (see Figure 3-4). Similar to Potter and Wilhelm (2020), I started by formulating equations for each relationship at -1 standard deviation (low) and $+1$ standard deviation (high) values of the explanatory and moderator variables to examine the moderating effects with simple slope statistics. The continuous interaction plot was then undertaken to further assess the relationships at the 10th percentile (low) and 90th percentile (high) values of the explanatory variable, along with the moderator variables at the 25th percentile (low) and 75th percentile (high) values. Following the approach, the nature of the relationships within the interaction plots could be observed without being affected by the potential impact of outlier firms (Potter & Wilhelm, 2020). Regarding the moderating effect of in-degree centrality, in line with H3, I observed that in-degree centrality positively moderates the effect on the association

between sustainability commitment and sustainability performance. However, it is also indicated that in-degree centrality weakens the relationship between sustainability commitment and sustainability performance (i.e. showing the negative moderating effect). Therefore, to amplify the effects on the interaction plot, I further examined the relationships at the 10th percentile (low) and 90th percentile (high) of the explanatory variables, along with the moderator variables at the 10th percentile (low) and 90th percentile (high) values. The result from the interaction plot reveals that the negative moderating effect of in-degree centrality on the relationship between sustainability commitment and sustainability performance would be most likely emerging only if the level of in-degree centrality is high (see Figure 3-4).

Finally, regarding the moderating effects of out-degree centrality, the results shown in Model 4 demonstrate that the out-degree centrality would have a positive moderating effect on the relationship between sustainability commitment and sustainability performance. As illustrated in the interaction plot (see Figure 3-5), the positive relationship moderating role is observed only when firms have a high level of out-degree centrality.



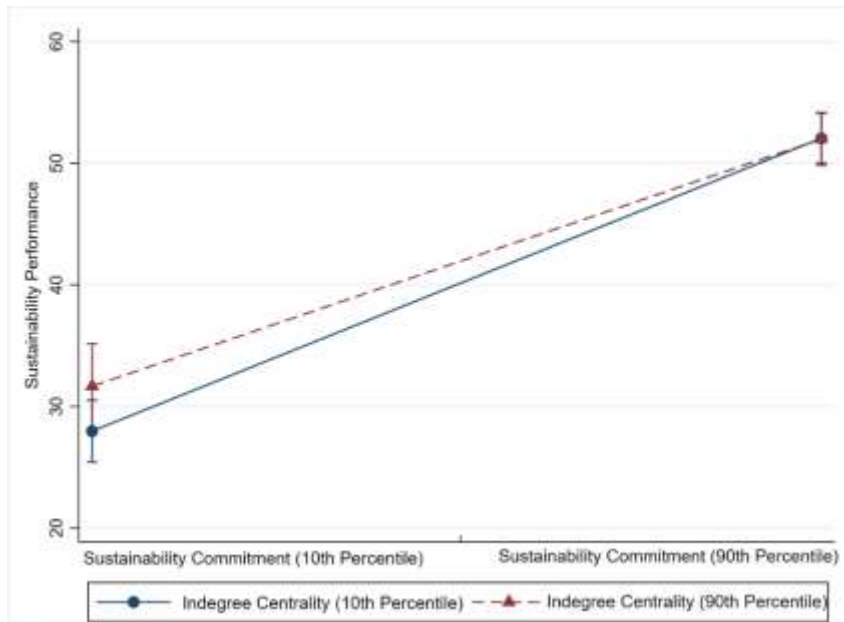


Figure 3-4 Moderating effect of in-degree centrality (Sustainability Commitment)

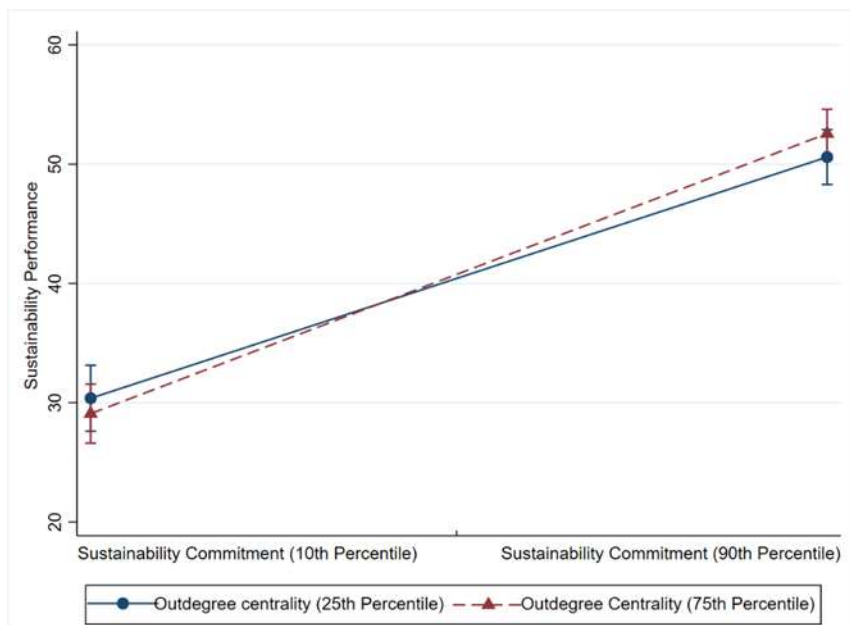


Figure 3-5 Moderating effect of out-degree centrality (Sustainability Commitment)

3.4.3 Robustness check

Additional analyses were conducted to ensure the study's results remain stable even when considering alternative measures and varying sampling criteria. First, in the sample of firms, there were some observations of missing data. I adopted the similar approach recommended by Gentry and Shen (2013) and replaced missing values with an average value in the main analysis (reported in Table 3-5). I also adopted a different measurement of firm size by using the natural log of total assets in a different year as a robustness check. I reran the analyses using the same OLS regression. The conclusions remain the same. Results of this alternative model are illustrated in Table 3-5.

Table 3-5 Robustness check

VARIABLES	Model 1	Model 2	Model 3	Model 4
Controls				
Firm Size	6.024*** [0.000]	3.191*** [0.000]	3.227*** [0.000]	3.260*** [0.000]
Firm Age	2.106** [0.020]	2.348*** [0.001]	2.384*** [0.001]	2.323*** [0.001]
Firm Sales Growth	-2.658 [0.129]	-1.495 [0.276]	-1.551 [0.256]	-1.621 [0.234]
Supplier Concentration	6.976 [0.116]	4.903 [0.159]	4.56 [0.188]	4.376 [0.205]
Power over Supplier	-0.570*** [0.000]	-0.416*** [0.001]	-0.409*** [0.001]	-0.405*** [0.001]
Main Effects				
Supply Network Interconnectedness		6.890* [0.054]	7.567** [0.034]	7.719** [0.030]
Sustainability Commitment		0.293*** [0.000]	0.303*** [0.000]	0.282*** [0.000]
In-degree Centrality		52.062 [0.213]	300.097** [0.021]	290.413** [0.025]

Out-degree Centrality	639.753	743.398	-1600	
	[0.374]	[0.300]	[0.283]	
Moderation Effects				
Sustainability Commitment*In-degree Centrality		-3.406**	-3.201*	
		[0.043]	[0.057]	
Sustainability Commitment*Out-degree Centrality			47.391*	
			[0.072]	
_cons	-16.403***	-10.547**	-11.805**	-10.759**
	[0.003]	[0.022]	[0.011]	[0.021]
N	304	304	304	304
adj. R^2	0.344	0.605	0.609	0.612

p-values in brackets

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

3.5 Discussion and conclusions

This study has sought to shed light on the often-invisible connectivity patterns of supply networks in which firms are embedded (Bellamy et al., 2014; Potter & Wilhelm, 2020) and their role in firms sustainability performance. Using a supply network dataset consisting of 18,943 firms and 103,632 contractual links in the automotive industry, the study revealed that the interconnectedness of the supply network in which a firm is embedded is positively associated with its sustainability performance. In addition, the research further demonstrated the moderating role of degree centrality as one of the most relevant supply network structural properties (Kim et al., 2011) in sustainability performance. Specifically, I showed that a firm's level of connectivity moderates the relationship between its commitment to sustainability and sustainability performance. With firms being held accountable for the sustainability behaviour and performance of their upstream suppliers (Hartmann & Moeller, 2014; Kim & Davis, 2016), I ascertained the number of network ties regarding the upstream suppliers and downstream customers could draw various implications in realising and achieving the firm's sustainability goals. The findings are summarised in Table 3-6. In light of the analyses, I now reflect on the hypotheses and demonstrate several important theoretical and practical implications.

Table 3-6 Summary of findings

Hypothesis	Factor(s)	Impact on Sustainability Performance	Support
1	Sustainability Commitment	Positive	Yes
2	Supply Network Interconnectedness	Positive	Yes
3	In-degree Centrality*Sustainability Commitment	Positive	No
3-competing	In-degree Centrality*Sustainability Commitment	Negative	Partially Yes

3.5.1 Theoretical implications

The study also adds several contributions in the existing literatures by tackling the interface between supply network structure and sustainability by examining how a firm could manage and benefit from its supply network to achieve the sustainability goals. Previous research has established the importance of collaborative processes in which firms engage with various supply chain members in developing sustainability capabilities or introducing sustainability innovations (e.g. Arora et al., 2020; Beske & Seuring, 2014). Similarly, existing literature suggests that firms form linkages with different members to communicate, monitor, and assess the sustainability targets (e.g. Tachizawa & Wong, 2014). This study extends this body of work by examining how the structure of supply networks in which firms are embedded can facilitate or impede these mechanisms. The results of H1 illustrate that the degree to which supply network partners of a firm are connected to each other positively influences its sustainability performance. This finding also aligns with the evidences in the literatures, demonstrating that highly interconnected supply networks foster collaboration amongst network members (Koh et al., 2012; Miemczyk et al., 2012; Villena & Gioia, 2018) and enforce shared sustainability values and norms among members (Fontana & Egels-Zandén, 2018).

Consistent with the existing literature, the results of H2 provide evidence that a firm's higher level of commitment to sustainability is associated with a higher sustainability performance. This finding supports the evidence in the literature that firms' commitment to environmental and social sustainability leads to the adoption of sustainability-oriented logic of business (Dahlin et al., 2020) and, therefore, can positively contribute to effective sustainability practices implementation in driving firms' sustainability performance (Chen & Chen, 2019; Cheng, 2020).

The study also provides evidence that while sustainability commitment can enhance sustainability performance, this association is contingent on the firm's

centrality in the supply network. Particularly, the result of H3-competing illustrates that the number of network ties to upstream suppliers and downstream customers play a unique and different role in moderating the relationship between sustainability commitment and sustainability performance. The finding also consistently supports the evidence in previous literatures that upstream suppliers and downstream customers play different roles in facilitating the knowledge and product flow in the network and, thus, have different implications for a focal firm in achieving its strategic objectives (e.g. Potter & Wilhelm, 2020; Rudberg & Olhager, 2003). The results of H4 reveal that a firm's out-degree centrality positively moderates the effect on the association between sustainability commitment and sustainability performance. The finding shows that firms with strong sustainability commitment capitalise on their exposure to a wider range of customers' sustainability demands and practices to learn about sustainability trends (Vurro et al., 2009) and benefit from an economy of scale through aggregating their customers' environmental and social requirements.

Contrary to out-degree centrality, the partial support for H3-competing provides some evidence that the moderating effect of in-degree centrality on the relationship between sustainability commitment and sustainability performance is negative. The interaction plot illustrates the detailed information (Figure 3.2) and indicates that a large supply base weakens the positive association between the firm's sustainability commitment and sustainability performance. The negative moderating effect of in-degree centrality supports the evidence in the literature that coordinating and incorporating a wide range of inputs from upstream networks create a high operational burden for firms with high in-degree centrality (Kim et al., 2011). Research also suggests that firms with many upstream ties need to orchestrate extensive monitoring processes to evaluate supply network members' sustainability performance and, thus, are less efficient in tracking sustainability-related data and achieving their sustainability goals (Kim & Davis, 2016; Vachon & Klassen, 2006).

3.5.2 Managerial implications

The study also gives multiple suggestions for managers that seek to enhance firms' sustainability performance. First, managers should acknowledge the importance of the supply network connectivity patterns in which their firms are embedded, beyond the portfolio of dyadic relationships. Investment in mapping of supply networks and visibility into the network structure (Choi et al., 2020) would help managers to proactively benefit from or minimise the harmful effects of the positions they take in their extended network of relationships towards achieving sustainability goals. Specifically, as firms engage in the diffusion and monitoring of sustainability targets or in collaborative activities to develop sustainability capabilities across their supply networks, acknowledging the structural characteristics of supply networks is imperative. For instance, in line with the findings, to achieve a higher sustainability performance, managers may be aware of fostering more interactions within the supply networks to effectively facilitate the sustainability-related information and knowledge flow and establish sustainability values and norms throughout the network. Additionally, while incorporating sustainability into the core business values, strategy and processes (sustainability commitment) lead to higher sustainability performance; managers also need to be mindful about the contingency role of supply network structural properties in realising its benefits. For instance, a high degree centrality position in upstream network may not be suitable where achieving sustainability goals does require extensive resources in helping suppliers develop sustainability capabilities (Alinaghian et al., 2021). However, the association between sustainability commitment and sustainability performance can be capitalised when firms occupy a central position in their downstream network.

Second, the research provides indications for managers to consider the position of supply network members in selecting and evaluating network partners. While traditionally the selection and evaluation of suppliers were mainly driven by their technical capabilities or performance, buying firms may now select their supplier based to the structural position they take within the supply networks (Choi & Kim, 2008; Yan et al., 2015). For managers whose focus is on achieving sustainability objectives, the study suggests benefits in assessing the supplier's supply network

interconnectedness, as well as the centrality on influencing sustainability performance.

3.5.3 Research limitations and directions for the future

Although this study provided some important insights, it still has multiple limitations that gives opportunities for future research. First, while the study investigates the structural properties of the supply networks in which firms are embedded, the quality of relationships which bond network members to each other (Alinaghian et al., 2019) may influence the way in which firms attain the sustainability goals. Future studies examining the role of supply network structure properties in firms' sustainability performance would benefit from incorporating relational and other network members' attributes. Second, the study uses cross-sectional data aiming to establish causal relationships through a 3-year time lag in the dependent variable. However, it is suggested that future studies feature a longitudinal dataset to further enhance the internal validity of these findings and investigate the role of supply network evolution in shaping firms' sustainability performance (Park et al., 2018). Third, the findings were drawn from a supply network dataset consisting of 18,943 firms from the automotive industry. Future research could enhance this findings' the external validity by corroborating the results in other settings with different industry characteristics. Fourth, while the CSR strategy score was included as a reflection of a firm's sustainability commitment, other important aspects could be considered to capture a firm's orientation to sustainability. Future studies could delve into other factors such as explicit incorporation of sustainability within the firms' strategic objectives (Lee & Hageman, 2018), which may be regarded as an appropriate variable to indicate firms' sustainability commitment.

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4 The role of neighbours' supply network structure in firms' sustainability controversies

Abstract

This study aims to empirically investigate how the structural properties of a focal firm's supply network, including the surrounding neighbours, influence their sustainability controversies. To examine the hypothesis, a supply network dataset was adopted consisting of 18,943 firms and 103,632 contractual links from the automotive industry. The sustainability controversies' data were obtained, using Thomson Reuters Eikon database, for 268 firms with publicly-reported available data. The results demonstrate a negative relationship between the interconnectedness of neighbours' network and its sustainability controversies, while a positive association exists between the centrality of a firm's neighbours and its sustainability controversies. Consistent with previous research, the results also reveal the contingency role of a firm's bridging in determining the sustainability controversies. However, this study shows that while there is a negative relationship between neighbours' interconnectedness and sustainability controversies, a firm occupying a bridging position positively moderates this relationship. This study extends the emerging discussion on the criticality of broader supply networks in sustainability literature by investigating the role of interfirm connectivity patterns of a real-world large-scale supply network.

Keywords: Sustainability controversies, Neighbours supply network structure, Social network analysis

4.1 Introduction

Sustainability controversies are broadly defined as “the conflicts that organisations face with stakeholders because the organisation’s behaviour along the supply chain damages the firm’s environmental or social dimensions of sustainability” (Tamayo-Torres et al., 2019, p. 3721). Firms engaging in harmful practices, such as modern slavery or environmental scandals along their supply chains, are at risk of incalculably damaging their reputation and market value (e.g. Bouzzine & Lueg, 2020; Dasgupta et al., 2006). In the automotive industry, firms like Vauxhall and BMW have faced controversies in their supply chains where the media accused both firms’ supply chains of being linked to the employed child workers who were unable to attend school (Guardian, 2016). Particularly, given more and more fragmented and internationally dispersed supply chains, firms’ reputation is increasingly being impacted by the network of direct and indirect supply chain relationships in which they are embedded (e.g. Harjoto & Wang, 2020; Lau et al., 2020).

In more recent times, an increasing number of studies have highlighted the huge importance of broader supply networks in driving sustainability (e.g. Alinaghian et al., 2021; Bellamy et al., 2020). These studies have revealed the importance of intricate, exclusive and often hidden connectivity patterns (i.e. the network structure) surrounding firms in their sustainability performance (e.g. Bellamy et al., 2020; Saunders et al., 2019). For instance, Gualandris et al. (2021) demonstrated the role of supply chain density (i.e. the cohesiveness of the distributed ties among supply chain members) and supply chain clustering (i.e. the extent to which suppliers form loosely coupled sub-groups that are nested within the extended supply chain) in enabling or constraining supply chain transparency (i.e. the disclosure of ESG information). Bellamy et al. (2020) have also demonstrated the contingency role of firms’ supply network interconnectedness and their bridging role in environmental disclosure. In these investigations, scholars have examined firms’ sustainability performance through various proxies such as sustainability transparency and disclosure (Bellamy et al., 2020; Gualandris et al., 2021) or sustainability outcomes (Ozcan, 2011). However, firms’ sustainability controversies appear to be stronger indicators of

sustainability performance as they capture both the importance and significance of the sustainability issues through market sensitivities (Tamayo-Torres et al., 2019). Studies suggest that market reactions are more pronounced when firms face controversies than good news (AIQ, 2021). Specifically, studies suggest that there is a clear negative market abnormal return when firms are subject to bad news (i.e. controversies) (AIQ, 2021). While the extant studies examining firms' sustainability performance have largely focused on firms' practices, they are inadequate in capturing the market reactions. Hence, the aim of study is to empirically examine how the structural properties of the supply network in which a firm is embedded can influence the firm's sustainability controversies.

Furthermore, in investigating such associations, the study shifts the focus to the focal firm's surrounding neighbours (i.e. a firm's network of direct connections). Two important properties of neighbours' network were examined, namely: 1) the interconnectedness of neighbours and 2) the centrality of neighbours. The interconnectedness of neighbours refers to "the degree to which supply network partners of a focal firm are connected to each other, and thus share direct links amongst themselves" (Bellamy et al., 2014, p. 360), whereas centrality of neighbours refers to the extent to which a focal firm is connected to firms that occupy central positions (Bonacich, 1987; Yan et al., 2015). This study suggests that the increased interconnectedness of the network in which a firm is embedded may benefit from the information redundancy due to the information reliability (Liang & Fu, 2019). Additionally, in such networks, neighbours could receive the network sanctioning due to the "close and friendly" network environment (Rowley et al., 2000; Villena et al., 2015). Conversely, when a firm is connected to central neighbours, its sustainability controversies could be positively associated. Such an influential position provides the focal firm with more aggregated power than its neighbours would be less controlled and supervised by its surrounding neighbours to reduce sustainability controversies (Yan et al., 2015). In addition, focal firms occupying such positions are considered to cause the issue of information asymmetry where they are able to dominate and control the information flow that only serves its own interest (Kim, 2019). Additionally, to further address the influence of neighbours' structural properties on sustainability

controversies, the study also considered the moderating role of bridging, that is, the extent to which a firm is located between high-degree nodes (Baruah & Bora, 2018).

In addition to testing the hypotheses, the study used a sample of 268 public listed firms. This sample included all firms from a secondary supply network dataset from the automotive industry that had disclosed their sustainability controversies data. The secondary supply network dataset, consisting of 18,943 firms and 103,632 contractual links between them, was used to calculate the network metrics for the 268 firms. This study also adopted the open-source software Gephi to visualise and calculate firm-level network structural metrics. Regarding the sustainability controversies data, I retrieved listed firms from Thomson Reuters Eikon for the 268 firms in the study.

The study adds contributions to the existing literatures on sustainable supply chain management, specifically the literatures investigating the role of supply network structural properties in two key ways. First, the study extends the emerging discussion on the criticality of broader supply networks in firms' sustainability by investigating the structural properties of firms' neighbours. Expressly, the study differentiated between two different network structure positions that have considered the neighbours' perspective. Moreover, the study determines the moderating effect of firms' bridging in sustainability controversies. Although prior literatures have highlighted the important role of the firm's bridging position and demonstrated that a firm's bridging role may be related to the sustainability aspect, the existing literature have not investigated the interplay of the firm's bridging position and neighbour's network structural properties in shaping sustainability controversies. Second, in investigating the role of supply network structural properties in a firm's sustainability, this study examined sustainability controversies that capture both a focal firm's sustainability practices and external reactions.

The remainder of this paper is organised as follows. First, I create a set of definitions for the constructs and develop theory linking the structural properties of supply networks in which firms are connected to their neighbours and

sustainability controversies. I then describe the dataset, variables, and measures. Third, I present the main results as well as the results of various additional analyses and robustness checks. Finally, the findings and the relevant implications are discussed before concluding with a discussion of research limitations and agenda for future research.

4.2 Theoretical background and hypothesis development

4.2.1 Supply networks and sustainability controversies

Controversies are broadly referred to as situations where actors disagree (or better, agree on their disagreements) (Venturini, 2010). The idea of disagreement should be considered broadly; controversies start when actors realise they do not communicate effectively and they end when they work out a mutual compromise to live together. Anything between these two extremes can be considered as a controversy (Venturini, 2010). Within the context of supply chains, scholars have defined sustainability controversies as the conflicts that firms face with various stakeholders throughout the supply chain whose practices and behaviour damage environmental or social sustainability (e.g. suppliers' labour exploitation, poor working conditions, pollution, destruction of natural habitats) (Tamayo-Torres et al., 2019). Scholars have further argued that failing to demonstrate integrity regarding environmental, social, and governance issues result in firms experiencing negative media coverage, such as involvement in scandals (Drempetic et al., 2020).

Whilst previous researchers have predominantly investigated the association between sustainability controversies and firms' value (Aouadi & Marsat 2018) and performance (e.g. Tamayo-Torres et al., 2019), very few research have obtained a network perspective to uncover the role of supply network structure in sustainability controversies. Recently researchers have begun to highlight the criticality of examining the relationship between the structural properties of supply networks in which a firm is embedded and sustainability controversies (e.g. mining resistance struggles; Aydin et al., 2017). Indeed, it is often stated that the focal firm is accountable for and affected by the actions of its network members. If its network members are undertaking inappropriate actions (e.g. disclosing

inaccurate information or unwilling to comply with the sustainability requirements), sustainability controversies will emerge (Tamayo-Torres et al., 2019).

4.2.2 Supply network structure

By adopting the SNA perspective, a network is comprised of nodes representing the network members and the linkages or ties that connect those (Borgatti & Li, 2009). In the context of supply networks, scholars suggest that the relative position of supply chain members within the overall patterns of network connectivity influences their behaviour and performance (e.g. Kim et al., 2011). For instance, previous literature has demonstrated the role of various supply network structural properties in the innovation (e.g. Bellamy et al., 2014) or effectiveness of risk management and resilience (e.g. (Kim et al., 2015; Ledwoch et al., 2018) of embedded firms. Furthermore, several studies in recent years have begun to highlight the role of supply network structural properties in explaining and investigating firms' sustainability performance (Alinaghian et al., 2021). Specifically, recent literature has suggested both the direct effect and moderating effect of supply network structural properties on the sustainability performance of the embedded firms (e.g. Bellamy et al., 2022).

This study examines two network structural properties focusing on the focal firm's surrounding neighbours that act as important determinants of firms' sustainability controversies: (1) the level of interconnectedness in the neighbours' network and (2) the centrality of firm's neighbours. First, it is posited that the interconnectedness of the neighbours and their centrality are associated with the focal firm's sustainability controversies. In addition, it is proposed that the focal firm's bridging position has a contingent effect on the relationship between its neighbours' structural properties and the firm's sustainability controversies. The hypothesised research model is presented in Figure 4-1.

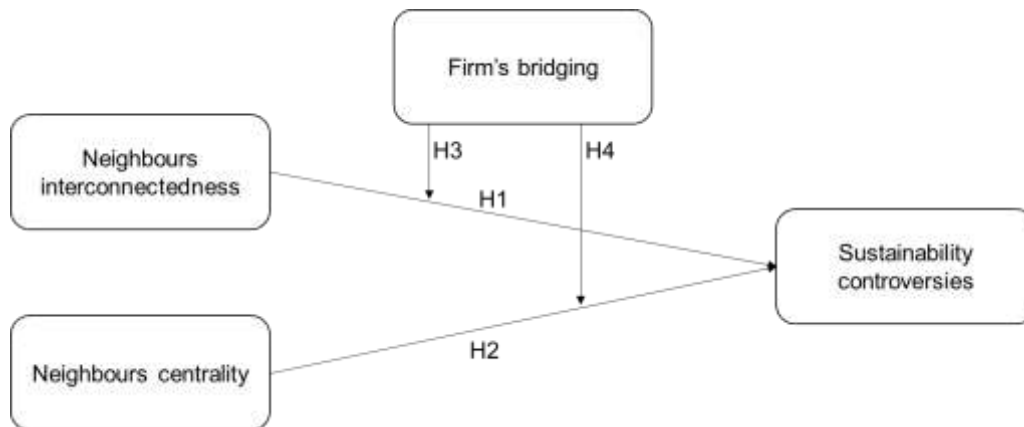


Figure 4-1 Hypothesised research model

4.2.3 Hypothesis model

4.2.3.1 Neighbours' interconnectedness and the focal firm's sustainability controversies

Neighbours' interconnectedness refers to "the degree to which supply network partners of a focal firm are connected to each other, and thus share direct links amongst themselves" (Bellamy et al., 2014, p. 360). Also referred to as network density, neighbours' interconnectedness represents the level of presence or absence of network ties between neighbours (Tong et al., 2018) and is operationalised through the ratio of the number of ties between a firm's neighbours to the total possible number of ties among neighbours (Borgatti and Halgin, 2011). Figure 4-2 also depicts the different levels of neighbours' interconnectedness that a firm could have in its supply network.

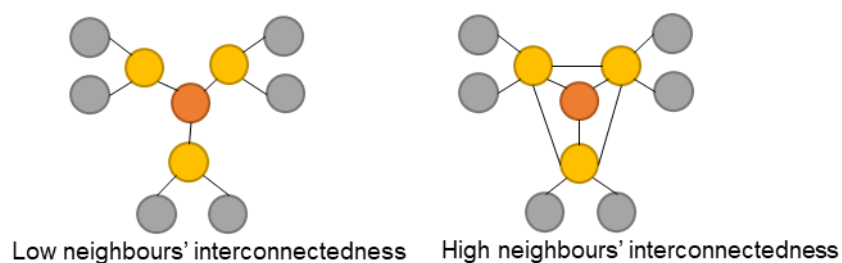


Figure 4-2 Illustration of levels of neighbours' interconnectedness

It is posited that a greater level of neighbours' interconnectedness negatively relates to the firms' sustainability controversies in the supply chain for the following reasons. First, dense ties among neighbours in a supply network lead

to information redundancy within the supply network. Although dense networks cause the exchanged information to become redundant, the redundant information enables the firms to validate the reliability of information and access robust information in terms of sustainability (Kim & Zhu, 2018). For instance, existing studies demonstrated that dense networks assist firms in obtaining a deeper understanding of a specific know-how and more exact information to detect and control potential sustainability misconduct in the network (Song et al., 2019). Furthermore, the information redundancy provides a common ground for firms to utilise the existing information towards problem solving and innovation (Gao et al., 2015). Thus, firms embedded in such dense network tend to create and develop problem-solving arrangements to reduce controversies quickly (Rindfleisch & Moorman, 2001).

Second, dense network tends to create close relationships among its members. In such networks, members tend to knit together and develop close collaborative engagements (Arora & Brintrup, 2021). In particular, these close relationships also engender familiarity and trust among network members, thus effectively promoting members to collect, extract, retrieve and transform the private information of others and increasing the visibility of operation processes (Song et al., 2019). In addition, firms embedded in dense networks tend to align their values and goals and can be highly beneficial for applying network sanctioning (Rowley et al., 2000). For instance, when a focal firm shares the commitment to sustainability with its interconnected neighbouring firms, neighbouring firms are more likely to hold each other accountable and support one another to meet focal firm's sustainability targets and complying with ethical guidelines (Kim & Zhu, 2018). This shared commitment minimises the potential for controversies arising from misleading or fraudulent sustainability claims. Therefore, in summary, I hypothesise:

H1. Neighbours' interconnectedness is negatively related to the focal firm's sustainability controversies.

4.2.3.2 Neighbours' centrality and the focal firm's sustainability controversies

Firms may not only be affected by the connectivity of neighbours (i.e. neighbours' interconnectedness), but are also associated with the centrality of its neighbours. The "neighbours' centrality" reflects the relative importance of the firms surrounding a focal firm (Bonacich, 1987). It is stated that a firm with many central neighbours is more likely to have a higher level of influence over other supply network members (Kim & Zhu, 2018) and accumulate valuable information within the network (Bloch & Jackson, 2016). Figure 4-3 displays the different level of neighbours' centrality, e.g. red node is the highest level, while the blue node ranks the second, black node ranks third and the yellow node is the least.

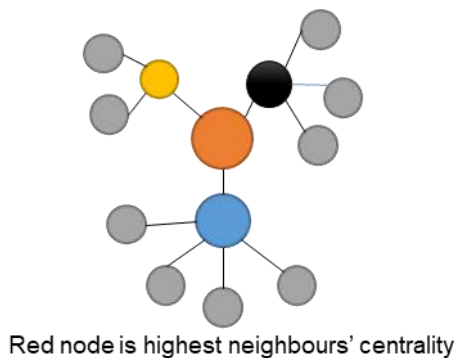


Figure 4-3 Illustration of the neighbours' centrality

I posit that neighbours' centrality in supply networks positively influences the focal firm's sustainability controversies for the following reasons. First, focal firms with high neighbour centrality tend to occupy a greater power position within their supply networks (Carnovale et al., 2017). Firms with greater power will be less controlled and supervised by its surrounding neighbours. For instance, neighbouring firms (e.g. suppliers) may find it difficult to manage the powerful focal firms (e.g. OEMs) when it comes to minimising potential controversies due to high power imbalances (Yan et al., 2015). In fact, such powerful firms may also have the possibility of causing a ripple effect in supply network. This is, indeed, in line with the claim that if the influential firms are not using or are misusing power to promote sustainable practices, other network members may also remain impassive to reduce sustainability controversies (Laari et al., 2022).

Second, a firm with a higher level of centrality amongst its neighbours' experiences information asymmetry (Kim, 2019). Although high neighbour centrality provides the firm with more information flows, firm may dominate and control the information flow that only serves its own interest. As a result, the diffusion of unbiased sustainability information is limited, and its neighbouring firms (e.g. lower-tier suppliers) may be short on correct sustainability resources and skills to help focal firm minimise the controversies (Laari et al., 2022). For instance, high neighbour centrality affects the likelihood of neighbours recognising and assimilating novel information (Laari et al., 2022) due to the inequitable information access, thus hindering the firm's capability to develop sustainable innovations to reduce controversies. Accordingly, I posit the following:

H2. Neighbours' centrality is positively related to firms' sustainability controversies.

4.2.3.3 Moderating role of firm's bridging

The conception of a firm's bridging (shown in figure 4-4) has been previously introduced by Burt (2004) (closely linked to the concept of structural holes) and Granovetter (1973) (closely linked to the concept of weak ties). The bridging position in the supply network provides firms with benefits of sourcing more information and opportunities from multiple, more often isolated, sections of a network (Carnovale et al., 2016; McEvily & Zaheer, 1999). This paper concentrates on how the bridging position interplay with other network structural properties (i.e. neighbours' interconnectedness and neighbours' centrality) impacts the focal firm's sustainability controversies.

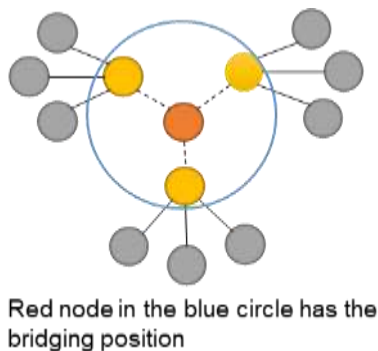


Figure 4-4 Illustration of a firm's bridging position

A focal firm's bridging could impact the relationship between the neighbours' interconnectedness and sustainability controversies for the following reasons. First, high level of firm's bridging strengthens the benefits of information redundancy that results from neighbours' interconnectedness. In other words, a bridging position represents a unique state where, due to the un-relatedness of the two groups in their supply networks, such position renders the firm access to heterogeneous and non-overlapping information (Burt, 2004). In fact, as the bridging firm becomes an important source for accessing heterogeneous sustainability-related information (Carnovale et al., 2017), the information benefits may help further foster the information utilisation and strengthen the impacts of neighbours' interconnectedness on the firm's sustainability controversies (Gao et al., 2015).

Furthermore, a firm in a bridging position further plays a monitoring role when it comes to sustainability controversies. More specifically, the unique position of connecting firms to multiple groups that are disconnected (Carnovale et al., 2017; Reagans & Zuckerman, 2008) help the firms establish trust among different network groups. Such trust could be crucial for monitoring firms because firms are more willing to share private information when the bridging firm is involved in their networks. The bridging position could also be beneficial for monitoring firms to jointly solve sustainability controversies more accurately. In addition, in the presence of firms' aligned values and goals in a highly dense network, the bridging firm could foster the facilitation of novel information and norms' propagation between firms. Therefore, it is further posited:

H3. A focal firm's bridging positively moderates the relationship between the neighbours' interconnectedness and its sustainability controversies.

I further posit that a focal firm's bridging position strengthens the influence of its neighbours' centrality on its sustainability controversies for the following reasons. First, the focal firm occupies a unique position in the network, which embodies both bridging and centrality attributes, and hence amplifies its power over its neighbours within the supply network. The extant literature showed that

disconnected and heterogeneous neighbours often lack trust and bridging firm may exacerbate the power imbalance influence among the neighbours in dealing with sustainability issues (Carnovale et al., 2017; Nyaga et al., 2013).

Second, the focal firm's bridging increases the scope and diversity of information, whilst the centrality of the firm's neighbours also indicates the firm has aggregated information within its network. By leveraging these two positions, the focal firms control more critical and comprehensive information comparing to its neighbours. However, they may selectively share information that aligns with their interests or agenda, while withholding or downplaying information that could highlight sustainability controversies. The negative consequences of this increased information asymmetry for the lower-tier firms are likely to be more problematic (Carnovale et al., 2016). This may hinder the focal firm to build consensus with its neighbouring firms to develop innovative solutions and reduce sustainability controversies (Jensen, 2011; Koka & Prescott, 2008; Yang et al., 2010). Hence, I hypothesise:

H4. A focal firm's bridging positively moderates the negative relationship between neighbours' centrality and its sustainability controversies.

4.3 Methodology

4.3.1 Research setting and data collection

This study utilised several data sources to create the network database, including the MarkLines Automotive Information platform, Thomson Reuters Eikon, the Bloomberg database, and online SDG Index. The automotive industry's progressive disverticalisation has led to a fragmented network of partners that firms rely on to supply products and services (Christensen, 2011; Sturgeon & Memedovic, 2010). Meanwhile, the industry itself is under increasing pressure to minimise negative impacts on the environment and society (Szász et al., 2021). Thus, this industry setting provides an appropriate research environment to investigate the role of supply network connectivity patterns in firms' sustainability controversies. Consequently, the supply network data was retrieved from the MarkLines database in 2014 and customer and supplier data were used to

determine connections between firms. Furthermore, each firm was then assigned a unique code, allowing for further identification of interconnections between upstream suppliers and downstream customers, resulting in a supply network of 18,943 firms and 103,632 links.

The data on sustainability controversies was obtained from the Thomson Reuters Eikon database. The Thomson Reuters ESG Controversies score was adopted to capture the firm's sustainability controversies across several indicators according to the reported data in the public domain. From the entire network of 18,943 firms, a sample of 304 firms with sustainability controversies data was first identified. The sustainability controversies data were retrieved in the year of 2017. I applied a 3-year time lag for the dependent variable; the reason for this is a firm's sustainability-related data in a current year is often affected by resources and initiatives that have been invested in preceding years. After this, the control variables' data were retrieved from the Bloomberg SPLC Function database. By observing the most recent snapshot of money flows between firms on the buyer (i.e. revenue) and supplier (i.e. cost), the SPLC database could be used to map firms with their suppliers and buyers (Kim & Davis, 2016). In accordance to the network data, I collected the control variables data from the year 2014 on the sample size of 304 firms from the early data collection stage. Finally, a sample of 268 firms was finalised in the main model after the data availability check. The description of these variables is shown in Table 4-1.

Table 4-1 Description of variables

Construct	Variable	Variable Type	Year	Measure	Datasource
Sustainability controversies	Negative ESG Controversies score	Dependent	2017	Negative ESG Controversies score (i.e. a company's exposure to environmental, social and governance controversies and negative events reflected in global media)	Thomson Reuters Eikon
Firm size	Natural log of market capitalisation	Control	2014	Firm size=ln(Market capitalisation)	Thomson Reuters Eikon
Firm age	Number of years from the dates of firm's founding	Control	N/A	Age	Thomson Reuters Eikon
Firm debt ratio	Firm debt ratio	Control	2014	the ratio of total debt and total equity	Thomson Reuters Eikon
Supplier concentration	Supplier concentration	Control	2014	the percentage of a focal company's cost of goods sold that is spent on its five main suppliers	Bloomberg
Firm power over direct suppliers	Firm power over direct suppliers	Control	2014	inventory turnover (cost of goods sold divided by the average inventory)	Thomson Reuters Eikon
Country	SDG score	Control	2014	a country's total progress towards achieving all 17 sustainable development goals (SDGs)	SDG Index
Neighbours' Interconnectedness	Local clustering coefficient	Independent	2014	Local clustering coefficient (i)=(2n _i)/(K _i (K _i -1))	MarkLines
Neighbours' Centrality	Eigenvector centrality	Independent	2014	$x_i = \frac{1}{\sum_{j=1}^n a_{ij} x_j}$	MarkLines
Focal Firm's Bridging	Bridging coefficient	Independent	2014	$\beta = \frac{\frac{1}{d(v)}}{\sum_{t \in N(v)} \frac{1}{d(t)}}$	MarkLines

4.3.2 Dependent variable

The Thomson Reuters ESG controversies scores are used as an indicator of the firm's sustainability controversies (Rajesh, 2020). The ESG controversies scores (e.g. a company's exposure to environmental, social and governance controversies and negative events reflected in global media) are considered to have a material impact on corporations (Refinitiv, 2022). The detailed description of the scores is shown in Table 4-2. The calculation formula of the ESG controversies score is based on various ESG controversy categories and shows the extent if a company involved in a scandal is penalised in the media (Refinitiv, 2022). The scores go beyond the widely applied ratings that merely focus on the firm's reporting and disclosure of sustainability (e.g. Bloomberg ESG data, Bellamy et al., 2020; Gualandris et al., 2021) by providing a transparent and objective measure of the firm's sustainability controversies. The ESG controversies' performance score data represents a relative score compared to the other firms in the sample. The controversies measure calculation method according to the database is shown below:

Equation 4—1

$$ESG \text{ controversies score} = \frac{\text{no. of companies with a worse value} + \frac{\text{no. of companies with the same value included in the current one}}{2}}{\text{no. of companies with a value}} \quad (4-1)$$

Based on the score calculation, companies having no controversies would attain a score of 100. It also means that the higher the scores, the better performance it played in sustainability controversies, displaying lower controversies. For instance, a high score (100) indicates that a firm is performing well compared to the other firms within the sample. A low score of, for example, 0.6 indicates that a firm is performing poorly (Refinitiv, 2022). Thus, given this definition and to simplify our statistical analysis, this study used the negative ESG controversies score to represent the sustainability controversies in this study.

Table 4-2 Thomson Reuters ESG controversies definition (Source: Refinitiv, 2022)

Category	Label	Description
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Community	Anti-Competition Controversy	No. of controversies reported in the media in relation to anti-competitive behaviour (e.g. antitrust and monopoly), price-fixing or kickbacks.
Community	Business Ethics Controversies	No. of controversies reported in the media in relation to business ethics in general, political contributions or bribery and corruption.
Community	Intellectual Property Controversies	No. of controversies reported in the media in relation to patents and intellectual property infringements.
Community	Critical Countries Controversies	No. of controversies reported in the media in relation to activities in critical, undemocratic countries that do not respect fundamental human rights' principles.
Community	Public Health Controversies	No. of controversies reported in the media in relation to public health or industrial accidents harming the health and safety of third parties (non-employees and non-customers).
Community	Tax Fraud Controversies	No. of controversies reported in the media in relation to tax fraud, parallel imports or money laundering.
Human Rights	Child Labour Controversies	No. of controversies reported in the media in relation to use of child labour issues.
Human Rights	Human Rights Controversies	No. of controversies reported in the media in relation to human rights issues.
Management	Management Compensation Controversies Count	No. of controversies reported in the media in relation to high executive or board compensation.
Product Responsibility	Consumer Controversies	No. of controversies reported in the media in relation to consumer complaints or dissatisfaction directly in relation to the company's products or services.
Product Responsibility	Customer Health & Safety Controversies	No. of controversies reported in the media in relation to customer health & safety
Product Responsibility	Privacy Controversies	No. of controversies reported in the media in relation to employee or customer privacy and integrity.
Product Responsibility	Product Access Controversies	No. of controversies reported in the media in relation to product access.
Product Responsibility	Responsible Marketing Controversies	No. of controversies reported in the media in relation to the company's marketing practices such as over-marketing of unhealthy food to vulnerable consumers.
Product Responsibility	Responsible R&D Controversies	No. of controversies reported in the media in relation to responsible R&D.
Resource Use	Environmental Controversies	No. of controversies related to the environmental impact of the company's operations on natural resources or local communities.
Shareholders	Accounting Controversies Count	No. of controversies reported in the media in relation to aggressive or non-transparent accounting issues.
Shareholders	Insider Dealings Controversies Count	No. of controversies reported in the media in relation to insider dealings and other share price manipulations.
Shareholders	Shareholder Rights	No. of controversies linked to shareholder rights infringements reported in the media.

	Controversies Count	
Workforce	Diversity and Opportunity Controversies	No. of controversies reported in the media in relation to workforce diversity and opportunity (e.g. wages, promotion, discrimination, and harassment).
Workforce	Employee Health & Safety Controversies	No. of controversies reported in the media in relation to workforce health and safety.
Workforce	Wages or Working Condition Controversies	No. of controversies reported in the media in relation to the company's relations with employees or relating to wages or wage disputes.
Workforce	Management Departures	Has an important executive management team member or a key team member announced a voluntary departure (other than for retirement) or been ousted?

4.3.3 Independent variables

Neighbours' interconnectedness. The degree to which a firm's neighbours are connected to each other is captured by the local clustering coefficient (i.e. node-level clustering coefficient). It is identified that this measure is used to reflect the extent to which a focal firm's neighbours form a cluster (i.e. network) within the supply network (e.g. Bellamy et al., 2014; Potter & Wilhelm, 2020). Furthermore, it also reflects the degree to which supply network neighbours of a firm are connected to each other (Borgatti & Halgin, 2011). Adopting the calculation method from Wasserman and Faust (1994), the formula of the local clustering coefficient for a focal firm i is presented as:

Equation 4—2

$$\text{Local clustering coefficient } (i) = \frac{2n_i}{K_i(K_i - 1)} \quad (4-2)$$

where n_i denotes the number of vertices connecting the K_i neighbours of the focal firm i . Similar to Basole (2016) and Potter and Wilhelm (2020), Gephi 9.2 network software is used to calculate the measure of the clustering coefficient.

Neighbours' centrality. The measurement of eigenvector centrality is adopted to reflect the neighbours' centrality. It is observed from previous study (Kim & Zhu,

2018) that the measurement of eigenvector centrality is proportional to the sum of the centralities of a firm's partners (i.e. neighbours). Thus, according to Kim and Zhu's (2018) similar approach, this study adopted Bonacich's (2007) eigenvector centrality formula and calculated the eigenvector centrality for the focal firm i as:

Equation 4—3

$$x_i = \frac{1}{\lambda} \sum_{j=1}^n a_{ij} x_j, i = 1, \dots, n \quad (4-3)$$

where x_i represents the eigenvector centrality of firm i , λ denotes the largest eigenvalue of an adjacency matrix, n is the number of vertices, $a_{ij} = 1$ if vertices i and j are connected by an edge, $a_{ij} = 0$, otherwise, and x_j is eigenvector centrality of partner firm j .

4.3.4 Moderating variables

The firm's bridging. I adopt the firm's bridging coefficient to determine the extent of how well the node is located between highly connected nodes. The bridging coefficient determines the extent to which a node is located between high degree nodes and assesses the local bridging characteristics in the neighbourhood (Hwang et al., 2006). In addition, it could reflect the flow input brought by the connection degree of the neighbours of the focal firm. Adapting the approach used by Hwang et al. (2006), a firm bridging coefficient is defined as:

Equation 4—4

$$\beta = \frac{\frac{1}{d(v)}}{\sum_{i \in N(v)} \frac{1}{d(i)}} \quad (4-4)$$

where $d(v)$ is the degree of a node v and $\delta(v)$ is the number of edges leaving the direct neighbour subgraph (i.e. subnetwork) of node v among the edges incident to each direct neighbour node i of node v .

4.3.5 Control variables

Several control variables were included that may be related to a firm's extent of sustainability controversies and they, respectively, are firm size, firm age, debt ratio, supplier concentration, firm's power over suppliers, and country. Control variables' data were obtained from three databases, i.e. Thomson Reuters Eikon database, Bloomberg database, and the online SDG index website.

Firm size, as measured by the natural log of market capitalisation, may influence firm sustainability controversies because larger firms tend to have more access to resources through their network of partners (Bellamy et al., 2014) and, therefore, more resourceful in tackling sustainability problems. Also, larger firms tend to overlook their supply chain issues due to the complexity of the supply network structure.

This study also controlled for the *firm age*, as calculated by the number of years since the dates that a firm's established to the current year of 2017. It is suggested that older firms are more likely to have inherited negligent sustainability practices and this could increase the likelihood of sustainability issues (Fan et al., 2021).

Additionally, I also controlled for *debt ratio*, as measured by the ratio of total debt and total equity controlling for the financial situation of firms, which may affect sustainability controversies. Previous studies also identified that firms having a higher level of debt ratio may have less capability to reduce sustainability controversies (Ng, 2018).

Furthermore, the study controlled for *supplier concentration*. Adopting the measure used by Kim and Davis (2016), supplier concentration is measured by the percentage of a focal firm's cost of goods sold that is spent on its top five main suppliers after sorting the suppliers. Firms that have more complex supply bases bear a heavier operational load with respect to monitoring and managing the supply chain network. Having complex supply chains can hamper the firm's ability to investigate its entire supply network and, therefore, become less effective in managing their sustainability controversies (Kim & Davis, 2016).

The study also controlled for the firm's *power over suppliers*, as measured by the inventory turnover as a proxy of a firm's power over its direct suppliers (Kim & Davis, 2016). Firms with more power over their suppliers have more control over the suppliers' decision making and leverage to demand sustainability standards. The inventory turnover data was retrieved from the Eikon database.

Lastly, the study controlled for the *Country*, as measured by a country's total progress towards achieving all 17 sustainable development goals (SDGs). Firms located in a country with higher sustainability standards might be forced to reduce the risk occurrence of a firm's sustainability performance (Huang et al., 2020).

4.4 Empirical results

All analyses were run using STATA Version 16.1. Table 4-3 summarised the relevant statistics (i.e. the descriptive statistics and simple correlation of all the variables).

Table 4-3 Descriptive statistics and correlation

	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10
1 Sustainability controversies	-86.7999	26.05313	1									
2 Firm size	25.50799	2.467569	0.0939 0.1204	1								
3 Firm age	4.171633	0.669487	0.0993 0.0968	0.0716 0.225	1							
4 Debt ratio	77.3363	83.17557	0.1918 0.0014	-0.101 0.0881	0.1056 0.073	1						
5 Supplier concentration	0.121788	0.157839	0.0728 0.2231	0.2697 0	-0.1 0.0821	0.025 0.6719	1					
6 Power over supplier	6.83101	4.512577	0.0065 0.9147	0.0057 0.9233	-0.022 0.7085	-0.0315 0.5956	0.0881 0.1325	1				
7 Country	77.73657	4.804467	0.0752 0.2077	-0.0396 0.5013	0.2008 0.0004	-0.015 0.7989	-0.1176 0.0404	-0.2159 0.0002	1			
8 Neighbours' interconnecte dness	0.105311	0.156467	-0.2057 0.0005	0.0978 0.0964	-0.1167 0.0423	-0.1326 0.0239	0.0868 0.1311	-0.0793 0.1756	0.1044 0.069	1		
9 Neighbours' centrality	0.048646	0.136355	0.4728 0	0.1166 0.0472	0.0751 0.1926	0.1811 0.002	0.0827 0.1504	0.1347 0.0211	-0.0047 0.9347	-0.2316 0	1	
10 Bridging	1.299421	4.599872	-0.0143 0.8115	-0.0862 0.1429	-0.0805 0.1624	-0.0469 0.4262	-0.0475 0.4091	-0.0613 0.296	0.0531 0.3563	-0.0187 0.7457	-0.0949 0.0987	1

I also checked for multicollinearity and ensured each predictor variable's VIF scores was below 10; this showed that multicollinearity issue does not exist in this dataset (Neter et al., 1996). Each VIF score for the dataset meets the condition (mean score of 1.16) (See Table 4-4).

Table 4-4 VIF of variables

Variable	VIF	1/VIF
Firm size	1.14	0.8757
Firm age	1.12	0.8932
Firm debt ratio	1.09	0.9192
Supplier concentration	1.13	0.8853
Firm power over direct suppliers	1.09	0.9141
Country	1.15	0.873
Neighbours Interconnectedness	1.36	0.7328
Neighbours Centrality	1.16	0.8656
Firm bridging	1.14	0.8751
Neighbours interconnectedness# Firm's bridging	1.32	0.7602
Neighbours centrality# Firm's bridging	1.09	0.9164
Mean VIF	1.16	

4.4.1 Main results

Table 4-5 presents the main results. The effects are displayed in sequence in models 1–4; this helps to ensure the stability of the model and confirm the robustness of any significant effect with the inclusion of other effects.

Table 4-5 Ordinary Least Square regression model-sustainability performance

VARIABLES	Model 1	Model 2	Model 3	Model 4
Controls				
Firm size	1.002	0.534	0.581	0.593
	[0.133]	[0.376]	[0.333]	[0.325]
Firm age	2.248	1.118	1.169	1.141

	[0.357]	[0.612]	[0.594]	[0.604]
Debt ratio	0.064***	0.035**	0.034*	0.034*
	[0.001]	[0.044]	[0.051]	[0.052]
Supplier concentration	6.825	6.374	6.555	6.554
	[0.513]	[0.498]	[0.483]	[0.484]
Power over supplier	0.116	-0.283	-0.316	-0.31
	[0.746]	[0.381]	[0.326]	[0.337]
Country	0.381	0.339	0.331	0.335
	[0.269]	[0.276]	[0.284]	[0.280]
Main Effects				
Neighbours' interconnectedness		-16.589*	-24.861**	-25.348**
		[0.082]	[0.016]	[0.015]
Neighbours' centrality		82.211***	81.096***	81.340***
		[0.000]	[0.000]	[0.000]
Firm's bridging		0.191	0.01	0.024
		[0.538]	[0.974]	[0.940]
Moderation Effects				
Neighbours' interconnectedness#Firm's bridging			4.937**	5.098**
			[0.040]	[0.038]
Neighbours' centrality#Firm's bridging				-28.983
				[0.726]
_cons	-157.949***	-135.501***	-135.460***	-135.866***
	[0.000]	[0.000]	[0.000]	[0.000]
<i>N</i>	268	268	268	268
adj. <i>R</i> ²	0.041	0.235	0.245	0.242

Model 1 is a base model including only the control variables. Specifically, Model 1 reports that only the firm's debt ratio is shown to positively affect the firm's sustainability controversies. Model 2 displays the main results of neighbours' interconnectedness, neighbours' centrality, and firm's bridging. The main results suggest that the posited neighbours' centrality has a positive effect on the focal firm's sustainability controversies ($p < 0.001$), while the hypothesised neighbours' interconnectedness has a negative effect on the firm's sustainability controversies ($p < 0.05$). Models 3 and 4 presents the progressive addition of the interactions in relation to H3 and H4. The full model is displayed in Model 4.

The full model shows a positive and significant relationship between neighbours' centrality and the level of sustainability controversies ($p < 0.001$), thereby providing the significant support for H2. Also, the negative association between neighbours' interconnectedness and sustainability controversies (H1) remains throughout to the full model ($p < 0.05$). Further, H3 that posited the interaction effect of neighbours' interconnectedness and firm's bridging on sustainability controversies performance is supported. However, the study failed to find any support for the Hypothesis 4.

4.4.2 Moderating effects

Additional insights into the significant moderating effect could be supplemented by adopting the interaction plot that displays the relationship between the variables of interest. The interaction plot was used for a more detailed examination of the moderating effects (see Figure 4-5). Similar to Potter and Wilhelm (2020), equations were created for each relationship at -1 standard deviation (low) and $+1$ standard deviation (high) values of the explanatory and moderator variables in order to analyse the moderating effects using simple slope statistics. Then, the continuous interaction plot was undertaken to further assess the relationships at the 25th percentile (low) and 75th percentile (high) values of the explanatory variable, along with the moderator variables at the 25th percentile (low) and 75th percentile (high) values. Following this approach, I could observe the nature of the relationships within the interaction plots without the potential influence of outlier firms (Potter & Wilhelm, 2020). Regarding the moderating

effect of bridging, in line with H3, I observed that a firm's bridging exerts a positive moderating effect on the relationship between neighbours' interconnectedness and sustainability controversies. The result from the interaction plot reveals that the positive moderating effect of a firm's bridging on the relationship between neighbours' interconnectedness and sustainability controversies would most likely emerge only where the level of a firm's bridging is high (See Figure 4-5).

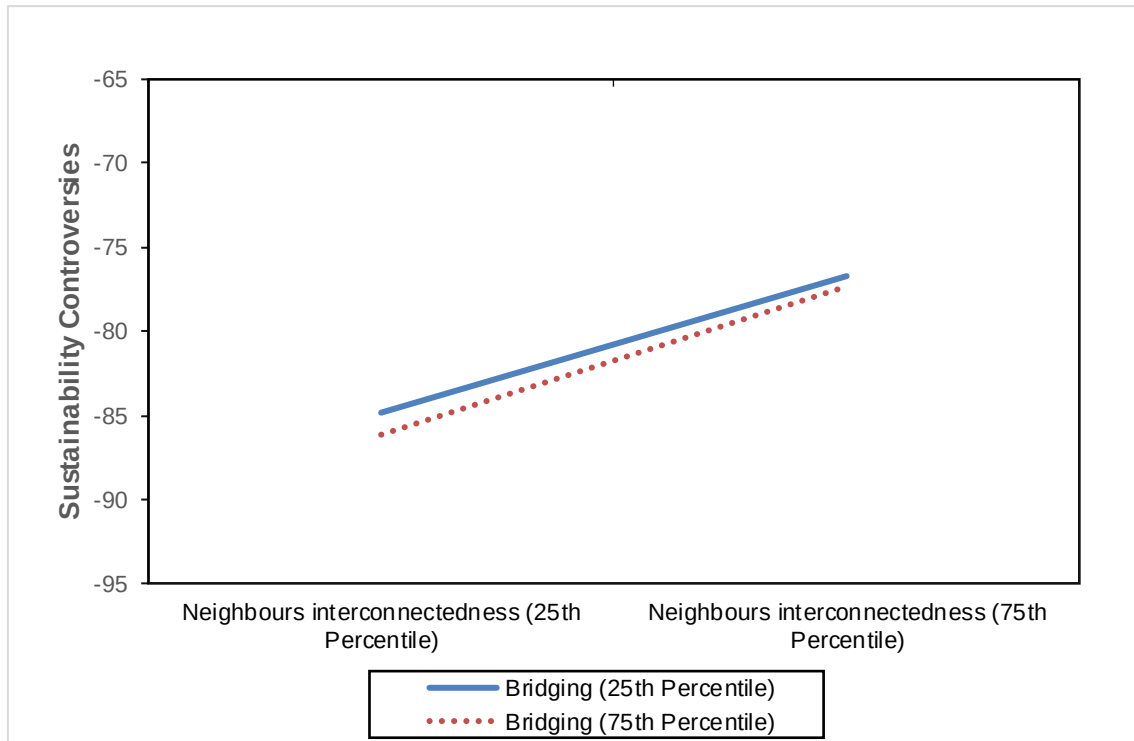


Figure 4-5 Moderating effect of bridging (Neighbours' Interconnectedness)

4.4.3 Robustness check

Additionally, this study further conducted another analysis to ensure the above results are still robust in terms of alternative measures and varying sampling criteria. In the sample of firms, there were some observations of missing data. I adopted a similar approach as recommended by Gentry and Shen (2013) and replaced the missing values with an average value in the main analysis (reported in Table 4-6). I also adopted an alternative measure of firm size by using the natural log of net sales in a different year as a robustness check. I reran the analyses using the same OLS regression. The conclusions remain the same. Table 4-6 presented the results of this alternative model.

Table 4-6 Robustness check

VARIABLES	Model 1	Model 2	Model 3	Model 4
Controls				
Firm size	0.809 [0.141]	0.308 [0.537]	0.351 [0.481]	0.365 [0.465]
Firm age	1.013 [0.585]	0.053 [0.975]	0.061 [0.971]	0.036 [0.983]
Debt ratio	0.051*** [0.002]	0.026* [0.088]	0.025* [0.099]	0.025 [0.102]
Supplier concentration	6.959 [0.462]	6.579 [0.441]	6.454 [0.447]	6.409 [0.451]
Power over supplier	0.091 [0.785]	-0.265 [0.380]	-0.295 [0.326]	-0.29 [0.336]
Country	0.327 [0.305]	0.412 [0.154]	0.404 [0.160]	0.405 [0.159]
Main Effects				
Neighbours' interconnectedness		-15.477* [0.066]	-22.823** [0.012]	-23.293** [0.011]
Neighbours' centrality		80.717*** [0.000]	79.707*** [0.000]	79.963*** [0.000]
Firm's bridging		0.135 [0.648]	-0.041 [0.893]	-0.025 [0.935]
Moderation Effects				
Neighbours' interconnectedness#Firm's bridging			4.792** [0.039]	4.964** [0.036]
Neighbours' centrality#Firm's bridging				-31.393 [0.694]
_cons	-141.676***	-129.590***	-129.277***	-129.544***

	[0.000]	[0.000]	[0.000]	[0.000]
<i>N</i>	304	304	304	304
adj. <i>R</i> ²	0.034	0.219	0.228	0.226

4.5 Discussion and conclusions

This study aims to reveal the often-invisible connectivity patterns of supply networks in which firms are embedded and their connection to surrounding neighbours in affecting sustainability controversies. These findings shed light on that the neighbours' interconnectedness is negatively associated with the focal firm's sustainability controversies, while neighbours' centrality positively affects its sustainability controversies. The research further demonstrates the moderating role of a firm's bridging; particularly, the empirical results showed the firm's bridging positively moderates the relationship between its neighbours' interconnectedness and sustainability controversies, while there is no significant effect on the association between neighbours' centrality and sustainability controversies performance. The overall findings are summarised in Table 4-7. In terms of these findings, I reflect on the hypothesis and demonstrate several important theoretical and managerial implications.

Table 4-7 Summary of findings

Hypothesis	Factor(s)	Impact on Sustainability Controversies	Support
1	Neighbours' Interconnectedness	Negative	Yes
2	Neighbours' Centrality	Positive	Yes
3	Neighbours' Interconnectedness # Bridging	Positive	Yes
4	Neighbours' centrality # Bridging	Positive	No

4.5.1 Theoretical implications

This research contributes to the existing literature by investigating how a firm can manage and benefit from its supply network structure and the relationship with its neighbours to reduce its sustainability controversies. The results for H1 illustrate that the degree to which network neighbours of a firm are connected to each other

is negatively related to its sustainability controversies. This finding confirms the evidence in the literature that being embedded in a highly interconnected network may enable the firms to validate the reliability of information in the supply chain (Kim & Zhu, 2018) due to information redundancy. Additionally, neighbours tend to knit together and become more collaborative rather than form a competitive relationship. Such a close relationship brings benefits, such as trust, utilisation of information, and aligned values and goals among neighbours, which is in line with previous scholars' viewpoints (Rowley et al., 2000; Song et al., 2019).

As expected, the result of H2 reveals that a greater level of neighbours' centrality is related to the higher level of sustainability controversies. This result is consistent with previous evidence in the literatures (Carnovale et al., 2017; Kim, 2019) that a greater level of firm neighbour centrality renders the firm to have aggregated power and information asymmetry. This finding indicates that the leading firm embedded in supply network with powerful neighbours could become more powerful and tend to be less controlled and supervised by others in terms of reducing sustainability controversies. The result also suggests that a firm with higher level of neighbours' centrality may increase the likelihood of having information asymmetry when it engages with other influential neighbours in supply chains as it becomes more powerful and may dominate the information flow that only serves its own interest (Laari et al., 2022).

In line with existing literature, the partial support for H3 also highlighted that the moderating effect of a firm's bridging on the relationship between neighbours' interconnectedness and sustainability controversies performance is positive. The positive moderating role of a firm's bridging supports the evidence in the literatures that a firm acting as a bridge could foster the information utilisation by introducing diversified information and act as a monitor relative to the two disconnected actors for firms embedded in a highly dense network (Gao et al., 2015). This finding suggests the degree of importance of such structural network power. However, this study failed to find support for H4 from the analysis' result. The reason for this situation may lie in the fact that both mechanisms (aggregated power and information asymmetry) were already very strong with the centrality

position of the firm. Yet the moderating role of bridging could provide additional power or novel information, which may become overlapped within the firm. Thus, the moderating role of bridging does not seem to bring a significant level of benefits to the focal firm.

In light of these results, the study, thus, further adds to the existing literature. First, the results confirm that a firm's neighbour network structure significantly affects firm sustainability controversies. Whereas prior scholars have begun to focus on a focal firm's structural properties (e.g. Bellamy et al., 2014; Potter and Wilhelm, 2020), this study adopts a neighbour's perspective and pays attention to the structural properties that are related to the firm's neighbours. This study obtained a more comprehensive understanding of the interplay between a firm and its neighbours and filled a gap that has been less studied by the existing literature. Despite that, compared to previous network studies (Bellamy et al., 2020) focusing on the sustainability aspects (e.g. environmental innovation), this study adopts sustainability controversies, which appear to be more accurate and specific. The use of sustainability controversies might be able to better reflect the dark side of sustainability performance, which can aid firms to influence their associations with other network members to perform sustainability.

4.5.2 Managerial implications

This study aims to provide a set of suggestions for managers and practitioners seeking to reduce the sustainability controversies of their firms and extended supply chains. Investment in mapping of end-to-end supply networks helps managers to gain a better visibility into the network structure of their partners with beneficial or harmful effects towards sustainability controversies. First, managers should be aware of the level of interconnectivity among their partner firms. Specifically, the findings suggest that the tighter a firm's neighbours' network is, the higher the robust information it can access. Thus, managers should proactively develop relevant relational and structural mechanisms to utilise this benefit and increase supply chain transparency. Meanwhile, this study's findings showed that a bridging position of the focal firm alleviates such benefits. Second, to obtain useful information and manage the flow, managers should be aware

that having more linkages with influential neighbours may cause both power asymmetry and information asymmetry in terms of reducing sustainability controversies. Under the guidance of these findings, it is also suggested for practitioners that they should make use of these specific firm positions to better manage their sustainability controversies. For instance, a firm's influential neighbours should put more efforts to monitor and control (e.g. sustainability audits) its actions to avoid the imbalance of power and information; also, firms need to work carefully with its heterogeneous neighbours when they are taking a bridging position as it may affect the existing benefits in the supply network. More specifically, the bridging firm should work collaboratively to identify common ground and shared goals with interconnected neighbours in terms of sustainability controversies.

4.5.3 Research limitations and agenda for future work

Although this study suggests some implications, it is still constrained in being able to suggest opportunities for future research. First, while the study adopted two main network structural properties of neighbours' interconnectedness and neighbours' centrality to investigate their influence on sustainability controversies, there could be other meaningful structural properties such as a participation coefficient and within module degree, capturing the firm's neighbours' linkages. Second, whilst adopting the Thomson Reuters ESG controversies score as a reflection of a firm's sustainability controversies, future research needs to differentiate the specific dimensions (e.g. community, human rights, product responsibility, etc.) of sustainability controversies to further capture the firm's sustainability controversies. Third, the findings were drawn from a supply network dataset consisting of 18,943 firms in the year 2014. It is expected that future research could improve the external validity of these findings by corroborating results in other time scales and contexts to monitor the supply network structural changes and their influence on sustainability controversies, e.g. using the panel data to investigate the influence change.

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5 Conclusion

This aim of this thesis was to investigate the role of supply network structure in driving sustainability performance. In accordance with the principal research question, several research objectives were stated to reach this thesis's aim. To begin with, Chapter 2 addressed the first research objective. Paper 1 in Chapter 2 adopted a SLR and the underpinning effects of the different network attributes in supply chain sustainability were synthesised and evaluated throughout the literatures. In particular, this SLR has distinguished between two network attributes (i.e. relational attributes and structural attributes) in affecting the sustainability performance at two levels (i.e. firm level and network level). Specifically, this paper uncovered their individual and interactive effects on both environmental and social dimensions of sustainability in supply chains. Thus, it has provided insights of current state of the art in the role of networks in supply chain sustainability management. Furthermore, this review paper identified different units of analysis, i.e. focal firm level and network level. Building upon that, several theoretical propositions in relation to supply chain sustainability that goes beyond the dyadic relationship were developed. These propositions, thus, contribute to future studies in this area and set the ground for the empirical section of this thesis.

The second research objective was addressed in Chapter 3. This study sought to shed light on the often-invisible connectivity patterns of supply networks in which firms are embedded and their role in firms' sustainability performance on the empirical grounding. Using a real-world and large-scale supply network dataset in the automotive industry, this chapter further reinforced the findings of the literature review and demonstrated how supply network structural properties affect the firm's sustainability performance differently. It also distinguished between the upstream ties and downstream ties that play different roles in facilitating the knowledge and product flow in the network and, thus, have different implications for a focal firm in achieving its strategic objectives.

Different from the Chapter 3's research, Chapter 4 addressed the third objective, confirming that a firm's neighbours' network structure could significantly affect

firm sustainability controversies. By adopting a neighbour's perspective, this chapter provided a more comprehensive understanding of the interplay between a firm and its neighbours, thus adding more contributions to the existing literature. Additionally, the use of sustainability controversies might better be able to reflect the dark side of sustainability performance and help firms to leverage their connections with other network members to perform sustainability.

Although Chapter 3 and Chapter 4 adopted similar secondary databases and used the OLS regression analysis, the use of different hypothesised models provided different results and indications. The results in Chapter 3 demonstrated that the level of a firm's sustainability commitment is positively related to its sustainability performance. This finding strengthens evidence in the literature that firms' sustainability commitment leads to the adoption of sustainability-oriented logic of business (Dahlin et al., 2020) and, therefore, positively contributes to the effective implementation of sustainability practices and firms' sustainability performance (Chen & Chen, 2019; Cheng, 2020). Meanwhile, it is also revealed that the interconnectedness of the supply network in which a firm is embedded positively affects its sustainability performance. This suggested that highly interconnected supply networks foster collaboration amongst network members (Koh et al., 2012; Miemczyk et al., 2012; Villena & Gioia, 2020) and enforce shared sustainability values and norms among members (Fontana & Egels-Zandén, 2018). In a different vein, Chapter 4 uncovered that neighbours' interconnectedness is negatively related to its sustainability controversies. Initially, it appears to contradict the findings presented in the preceding chapter; however, a high level of neighbours' interconnectedness may benefit from information redundancy and close relationships. Thus, it provided an opposite effect in contrast to the results in Chapter 3.

Despite that, Chapter 3 further revealed that the contingent role of the firm's centrality (i.e. in-degree centrality and out-degree centrality) in the supply network plays differently in moderating the relationship between sustainability commitment and sustainability performance. This result distinguished between the role of upstream ties and downstream ties, indicating that coordinating and

incorporating a wide range of inputs from upstream networks create a high operational burden for firms with high in-degree centrality (Kim et al., 2011). On the contrary to Chapter 3, it was determined in Chapter 4 that a firm's bridging positively moderates the relationship between neighbours' interconnectedness and sustainability controversies. This finding concurs with the evidence in previous literatures that a bridging role could help firms obtain novel information and monitoring benefits relative to the two disconnected actors for firms embedded in a highly dense network (Weiner & Hannum, 2013). This finding suggests the great importance of such structural network power. Overall, the results in Chapter 3 and Chapter 4 show a variety of structural properties that would lead to different sustainability outcomes and could be positive or negative.

5.1 Practical implications

Given the research findings in Chapter 2 to Chapter 4, this thesis offers several practical implications. Chapter 2 highlights the importance of adopting a network lens in supply chain sustainability and firms should put emphasis on the two attributes (i.e. relational attributes and structural attributes). Firstly, this study has provided practitioners with an analytical tool to visually characterise the structural properties of the firms' supply networks. In terms of this, firms should concentrate more on the structural investigation of embedded firms to drive sustainability. More specifically, it is imperative for practitioners to design relevant network structures when they apply various sustainability practices (e.g. monitoring, capability development) to achieve the sustainability. For instance, the high degree of centrality position tends to be not suitable where achieving sustainability goals may require substantial resources to support the lower-tier suppliers to develop sustainability capabilities. Given this, firms should consider delegating their management of sustainability to the first-tier suppliers occupying other important structural positions (e.g. high betweenness centrality position). Furthermore, review findings suggest forms of governance mechanisms (i.e. formal and informal mechanisms) that need to be implemented to achieve sustainability performance. For instance, a power-based mechanism may

enhance the monitoring performance of first-tier suppliers occupying high centrality positions.

In addition, results in Chapter 3 confirmed that structural properties (i.e. supply network interconnectedness) have a direct influence on the firm's sustainability performance. For instance, in a practical case of Japanese automobile supply network, a dense network in which each major assembler (e.g. Toyota) is firmly tied to a group of suppliers (Todo et al., 2016), could improve its sustainability performance of both assemblers and suppliers. Indeed, the firm's degree centrality interacts with sustainability commitment in shaping its sustainability performance. This unravels that although incorporating sustainability into a firm's core business values, strategy and processes (i.e. sustainability commitment) lead to a greater level of sustainability performance and managers also need to be mindful about the contingent role of supply network structural properties in realising its benefits. In other words, firms should acknowledge the importance of the supply network connectivity patterns in which their firms are embedded, beyond the portfolio of dyadic relationships.

Furthermore, it is identified in Chapter 4 that management of lower or indirect suppliers (i.e. neighbours) is often neglected. Their perceptions and values towards sustainability will greatly affect the implementation of sustainability and their understanding of green or sustainable supply chain management (SCM) and also influence the way they behave in the process of the supply chain, e.g. sourcing ethically in terms of environmental standards, enhancing employee welfare fairly, etc. Thus, this research calls for firms to consider the firm and its surrounding neighbours' network structural position in shaping sustainability. The results of Chapter 4 suggest that managers should be aware of the level of interconnectivity among their partner firms. For instance, the automotive OEM could utilise its interconnected suppliers and engage in collaborative relationships with them to source sustainability-related information to reduce its controversies. Furthermore, to obtain valuable information and control the flow, managers also need to be aware that sharing more information and balancing the power with influential neighbours is crucial. For instance, suppliers should aim to associate

themselves more with the central players (e.g. influential firms) instead of many small suppliers in their industries (Chowdhury et al., 2023), thereby expanding their access to more sustainability information and developing sustainable innovations to reduce controversies. Meanwhile, suppliers should proactively mitigate the information asymmetry when associating with these central players. Additionally, the results provide managers with practical insights that bridging firm (e.g. first-tier suppliers) could act as relay points to cascade the sustainability practices of focal companies to lower-tier suppliers and monitor the sustainability compliance to avoid misconducts within supply chains (Johnsen et al., 2022).

Thus, the importance of structural investigation provides indications for managers to consider the position of supply network members in selecting and evaluating network partners. While traditionally the selection and evaluation of suppliers were mainly driven by their technical capabilities or performance, buying firms may now select their supplier based on the structural position they take in the supply network (Choi & Kim, 2008; Yan et al., 2015). For instance, in Chapter 4's finding, it is observed that a bridging position of the focal firm could have the role of auditing and monitoring the highly interconnected firms. Despite this, managers should proactively develop relevant relational and structural mechanisms to improve supply chain transparency and manage the lower-tier suppliers (i.e. neighbours).

Lastly, this thesis provides implications for policy makers whose focus is on regulating firms to achieve sustainability objectives. Policy makers should try to work with influential firms or firms in a central position and regulate them to disclose accurate sustainability information. This type of collaboration and information disclosure will assist policy makers to issue accurate reports, guidelines, proposals, and frameworks for industries and external stakeholders.

5.2 Limitations and directions for future research

While the thesis has provided some notable insights, it is still restricted in how to suggest opportunities for future research.

5.2.1 Analytical approach

One limitation that presented itself is that this thesis only used cross-sectional data for both the network structural properties and sustainability performance. Also, to establish a causal relationship, a 3-year time lag for the dependent variable was applied. However, it is suggested that future studies feature a longitudinal dataset to further enhance the internal validity of these findings and investigate how sustainability performance changes when the network structure evolves over different years. Particularly, panel data analysis could be applied to observe the role of supply network evolution in shaping firm's sustainability performance (Park et al., 2018). Furthermore, difference-in-difference analysis (DID) could be adopted to observe and compare the changes in outcome over time. For instance, future study could collect supply network information (e.g. numbers of suppliers and customers connections) from supply chain databases (e.g. Bloomberg SPLC function) in different years over a certain period to examine the evolution of network structure in relation to the network performance.

5.2.2 Databases

Due to the issue of database accessibility, this thesis only used the scores from the Thomson Reuters ESG database for the variables of sustainability performance and sustainability controversies; this may affect the accuracy or create data bias regarding the results. Future studies could consider other databases (e.g. Bloomberg ESG database, Sustainalytics, Dow Jones Sustainability indices, etc.) to retrieve the sustainability data.

Additionally, we retrieved supply network data in the automotive industry only in 2014, however, supplier and customer information and connections and thus the network structure may have changed over time. For instance, the recent digitalisation of supply chains has led to the emergence of new actors (nodes) and different patterns of interconnectivity that may enable companies to address the new requirements of the sustainability differently. Specifically, future research could advise companies to use digitalisation to monitor misconduct in the supply chains. For instance, big data, diagnostics and tracking could be implemented to enhance the sustainability of products, services and processes (Melander &

Pazirandeh, 2019). Therefore, future research could consider updating the supplier and customer data in automotive industry to take into account of recent trends in supply chain in exploring the relationship between supply network structural properties and firms' sustainability performance.

5.2.3 Research setting

This thesis investigated the interrelationships between supply network structural properties and sustainability only in the automotive industry. Future research could enhance this thesis' findings' by further corroborating and extending the results beyond the confines of the automotive industry (e.g. digital technology) or by adopting a multi-industry research setting. Specifically, recent scholars (Gruchmann, 2022) have argued that digital technologies may replace the central actors in directly governing the resources and support sustainability achievement in supply networks. By delving into diverse industry settings, researchers could not only validate the robustness of the current results, but also unravel novel insights and trends that may provide broader practical implications regarding the sustainability performance.

5.2.4 Sample size

From a methodology point of view, one limitation in this thesis is related to the size of the sample for further statistical analysis. As the number of firms selected and filtered in the final sample are only around 300 firms, this may affect the data bias regarding the empirical results. Future research could consider expanding the sample size if the sustainability data are accessible and unrestricted. For instance, future studies could identify a focal firm's supply network from the start and gradually gather firms data in different tiers (e.g. even the raw suppliers) in the sample. By doing so, the sample size could be ensured at a multi-tier level and unbiased. Furthermore, future research could consider using an open-source project (e.g. GitHub) to share data real time. By doing so, the datasets could be further disseminated and future scholars could get access to a more diverse and sufficient large dataset.

5.2.5 Variables

5.2.5.1 Sustainability variables

Although this thesis focussed on the environmental and social sustainability performance; it did not distinguish between these two dimensions. Nonetheless, no empirical studies, yet, have differentiated the environmental and social sustainability performance from a network perspective. Hence, future research is required to investigate their different effects and provide relevant indications to policy makers or practitioners to issue reports and frameworks in terms of different dimensions of sustainability management.

Chapter 4 sought to unravel how the interplay of supply network structure and neighbours influence firms' sustainability controversies. While neighbours' performance plays a role in influencing firms' sustainability controversies, the study is limited in capturing this effect. Specifically, the operationalisation of neighbours' sustainability controversies has remained unexplored. Future research needs to include neighbours' performance variables by collecting and measuring the relevant metrics for the neighbours' sustainability controversies. For instance, a novel assessment or a benchmark should be created to help calculate the collective score of neighbours' sustainability controversies. Scholars could consider using primary data sources (e.g. via surveys, interviews etc.) if secondary data is not accessible, and develop relevant methodology to obtain the collective controversies performance of a focal firm's neighbours.

5.2.5.2 Network structural variables

Following the propositions developed in the systematic literature review paper, I investigated only a few firm-level structural properties (e.g. interconnectedness and centrality positions) in supply network and their influence in driving sustainability. This limited a more insightful investigation into other network-level structural properties (e.g. modularity) and future study should consider adopting more advanced structural properties to capture the network-level performance.

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APPENDICES

Appendix A Details of collected secondary data

A.1 Sustainability data

The secondary data related to sustainability was retrieved from Thomson Reuters Eikon database in ESG template mainly due to its accessibility. Although there are many databases in the market, e.g. Bloomberg ESG, Thomson Reuters Eikon, Corporate Knights Global 100, DJSI, ISS, Sustainalytics, etc (Betty et al., 2017). The author's on-campus library service only has Bloomberg ESG and Thomson Reuters Eikon ESG databases. In terms of these two databases, the Bloomberg ESG database has a few limitations comparing to the Thomson Reuters Eikon ESG database. Similar to Betty et al. (2017)'s summary, Table A.1-1 displayed the differences.

Table A.1-1 Bloomberg ESG database and Thomson Reuters Eikon ESG database comparison

ESG database	Background	Rating Scale	Methodology
Bloomberg ESG Data	1. ESG data collected for over 9,000 companies 2. Bloomberg Equities and Intelligence Services were integrated. 3. International scope 4. Under Financial Analysis (FA) and ESG Analysis, but scores are not unified and identical.	1. Out of 100 2. Provides scores from 3rd party rating agencies.	1. Looks at 120 ESG indicators
Thomson Reuters ESG Research Data	1. Thomson Reuters acquired Asset4 in 2009 2. Provides ESG data on over 6,000 companies 3. The first agency to provide raw ESG data to investors. 4. International scope	1. Percentile rank scores (has both percentages and letter grades from D- to A+)	1. Covers 400 different ESG metrics, electing 178 of the most relevant data points 2. Categories are weighted. 3. Updated every 2 weeks.

Consistent with the content in Table A.1-1, Figure A.1-1, A.1-2, A.1-3 and A.1-4 further display the screenshot of a firm's (i.e. 3M. Co) ESG dashboard from these two different databases. 3M. Co was simply selected here as it is the first company after sorting company's name alphabetically to provide an example of how the dashboard looks differently in two different databases.

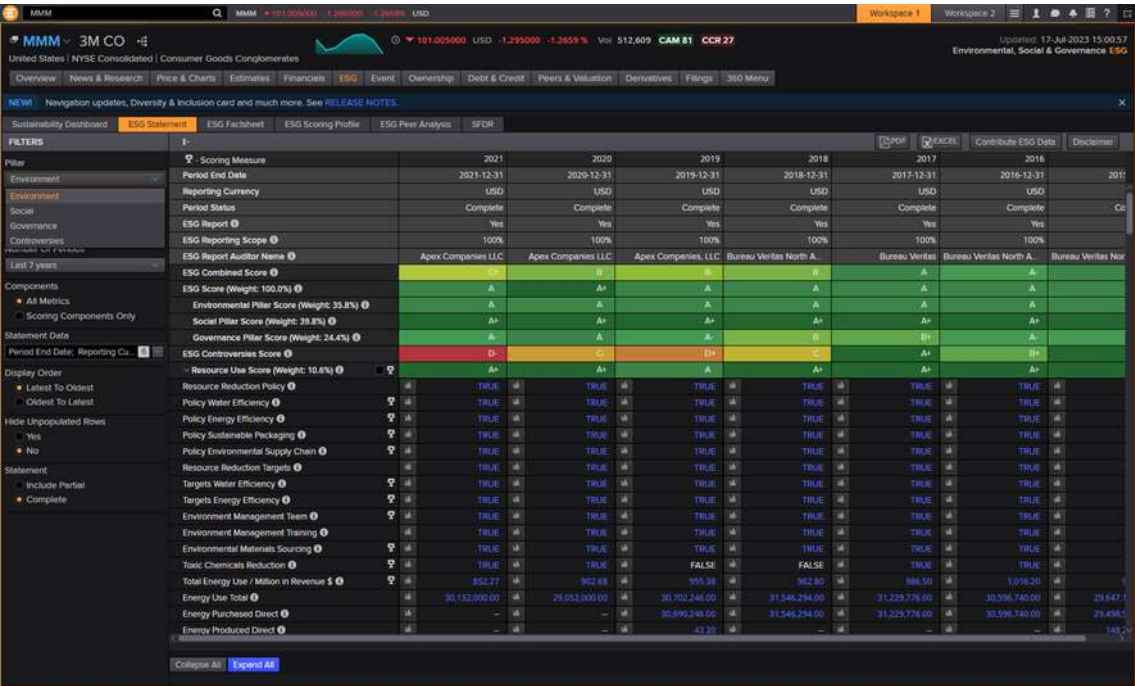


Figure A.1-1 Thomson Reuters Eikon ESG database dashboard screenshot

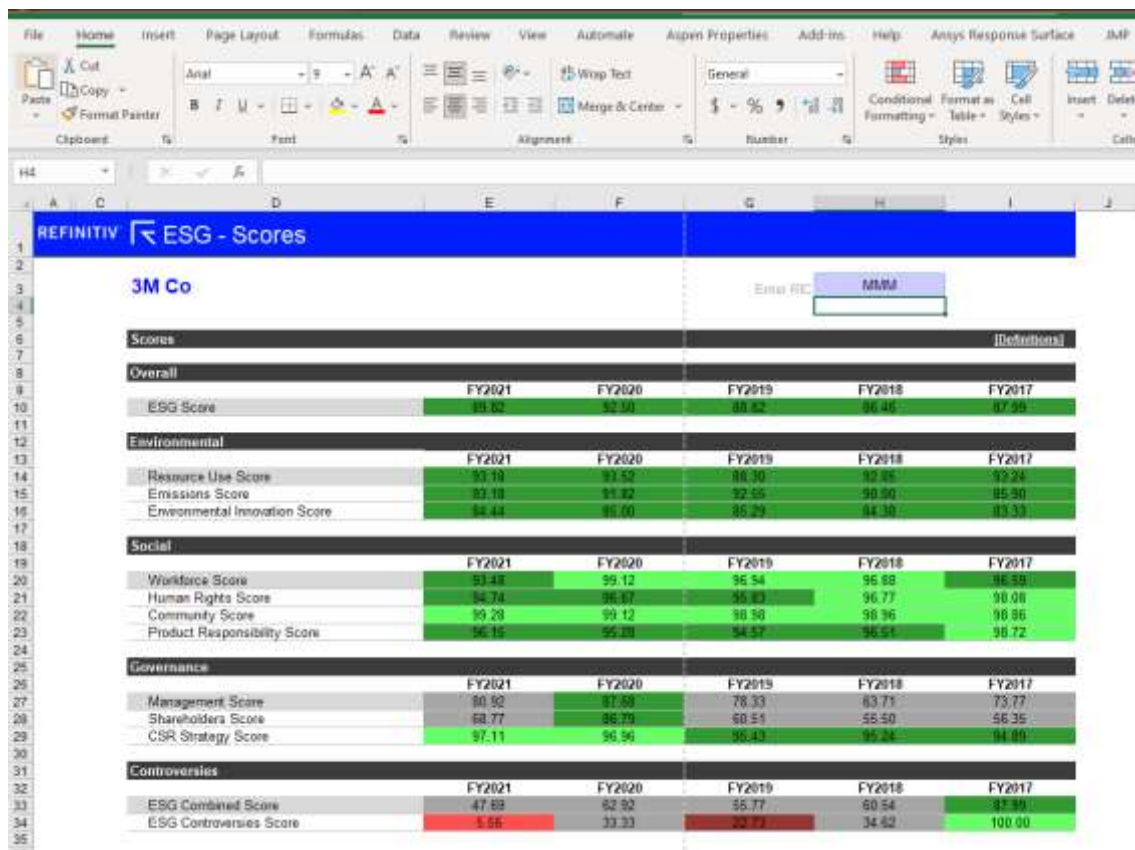


Figure A.1-2 Thomson Reuters Eikon ESG database dashboard screenshot (excel version)



Figure A.1-3 Bloomberg database ESG analysis dashboard screenshot (under ESG analysis)



Figure A.1-4 Bloomberg database FA dashboard "ESG tab" screenshot

More specifically, it is identified that figure A.1-3 and A.1-4 both allow the author to quickly review a company's ESG profile. However, Thomson Reuters Eikon ESG database provides a more comprehensive ESG data after the comparison, which allows the author to delve deeper and view a more complete set of ESG data.

A.2 Network data

Network data consists of 18,943 companies, which was retrieved from Marklines platform first, and then export it to excel sheet. In excel sheet, companies and its suppliers or customers were recorded in a "source-target" form to represent its relationship between each other (see Figure A.2-1 and A.2-2). After this, the author imports the "source-target" spreadsheet to Gephi software to calculate the relevant network metrics. The screenshot of Gephi software is also displayed in the figure A.2-3. Furthermore, Gephi software provided a visualisation of a network shape (see Figure A.2-4) consisting of those 18,943 firms. Meanwhile,

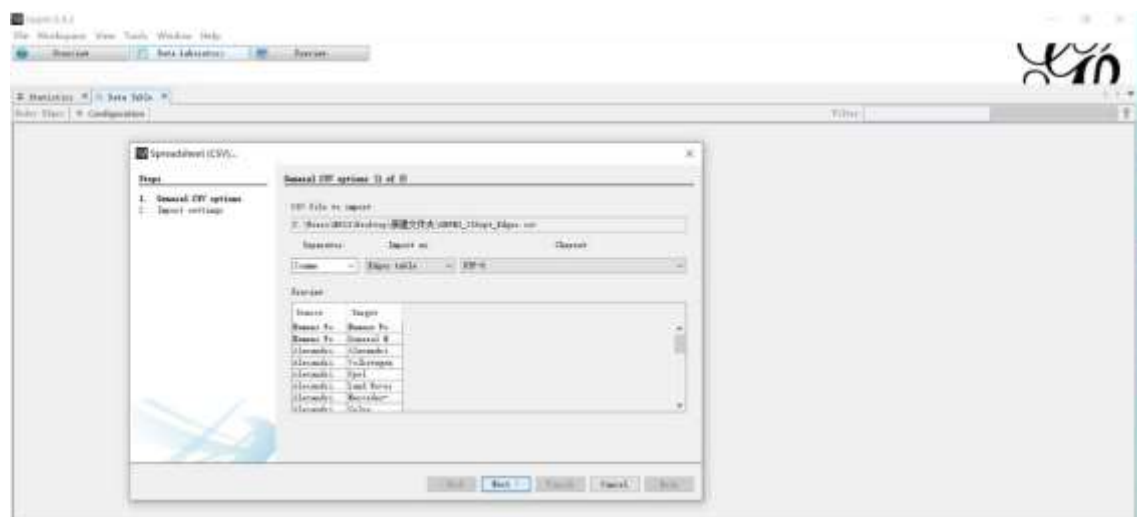
on the right side of the Gephi dashboard, it has various network metrics calculation buttons and enables the author to calculate the relevant network metrics. The calculation result of network metrics could be found in the “data laboratory” tab in Figure A.2-5.

	A	B	C
1	Source	Target	
2	Hamenz F	Hamenz For German	
3	Hamenz F	General Motors (GM	
4	Alexandria	Alexandria Automoti	
5	Alexandria	Volkswagen	
6	Alexandria	Opel	
7	Alexandria	Land Rover	
8	Alexandria	Mercedes-Benz	
9	Alexandria	Volvo	
10	Alexandria	VW-SEAT	
11	Alexandria	Mazda	
12	Alexandria	Fiat	
13	Alexandria	Ford Motor Compan	
14	Alexandria	Audi	
15	Auto Cool	Auto Cool	
16	Auto Cool	Opel	
17	Auto Cool	BMW	
18	Auto Cool	Citroen	
19	Auto Cool	Daewoo	
20	Auto Cool	Hatz	
21	Auto Cool	KIA Motor	
22	Auto Cool	Mercedes	
23	Auto Cool	Peugeot	
24	Auto Cool	Suzuki	
25	Dr. Greich	Dr. Greiche & Co	

Figure A.2-1 Companies relationship construction (part 1)

	A	B	C	D	E
103612	Hangzhou	Hangzhou Sagara Plastics Co. Ltd.			
103613	Hangzhou	Yazaki Parts			
103614	Ningbo Qi	Ningbo Qiaoshi Rubber & Plastic Co. Ltd.			
103615	Ningbo Qi	FAW Haima Motor			
103616	Ningbo Qi	Zhongxing Automobile			
103617	Ningbo Qi	Jinbei Automotive			
103618	Ningbo Qi	Lifan Group			
103619	Suzhou In	Suzhou Inoac Elastomer Co. Ltd.			
103620	Suzhou In	Nissan			
103621	Suzhou In	Toyota			
103622	Suzhou In	SHARP			
103623	Ningbo Gc	Ningbo Goodtime SCI & Tech Co. Ltd.			
103624	Ningbo Gc	General Motors (GM)			
103625	Ningbo Gc	Chrysler			
103626	Ningbo Gc	Honda			
103627	Ningbo Gc	Toyota			
103628	Ningbo Gc	Ford Lio Ho Motor			
103629	Jiaxing Mi	Jiaxing Minrong Autotive Parts Co. Ltd.			
103630	Jiaxing Mi	Dongfeng Honda Automobile Co. Ltd.			
103631	Jiaxing Mi	Dongfeng Honda Automobile Co. Ltd.Source			
103632	?Hamenz I	General Motors (GM)			
103633	?Hamenz I	?Hamenz For German Tech. Ind. (S.A.E.)			

Figure A.2-2 Companies relationship construction (part 2)



figures below. The author also used 3M. Co (i.e. MMM) company's data as an example to illustrate how the data was retrieved from the databases.

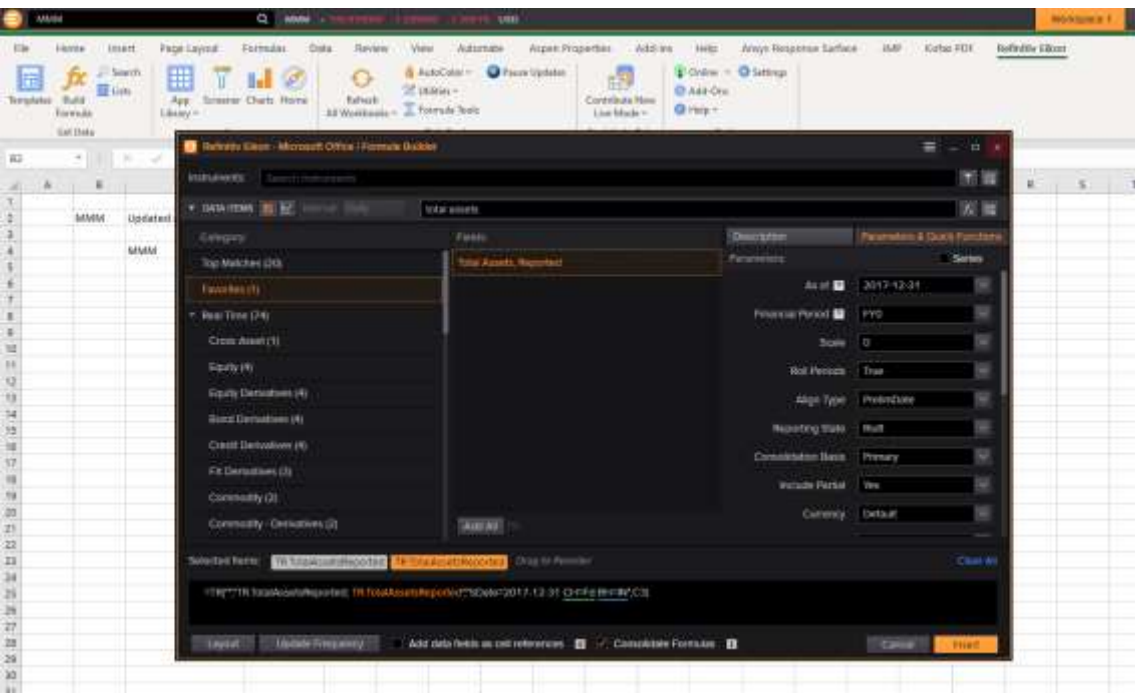


Figure A.3-1 Firm size

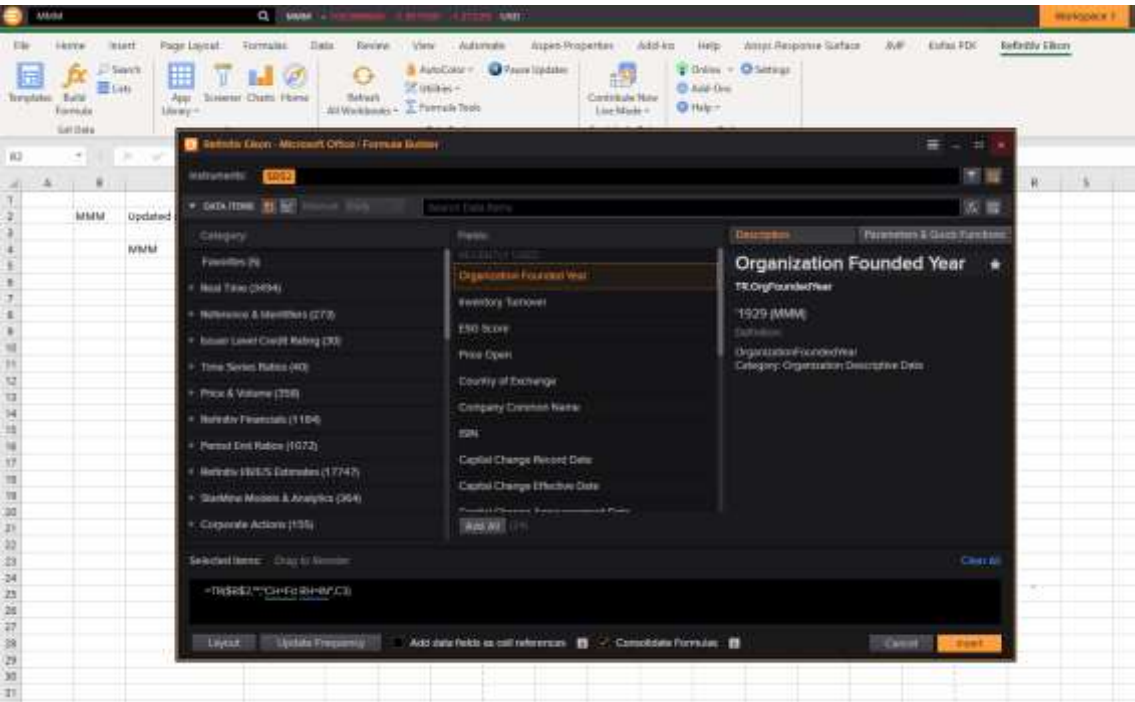


Figure A.3-2 Firm age

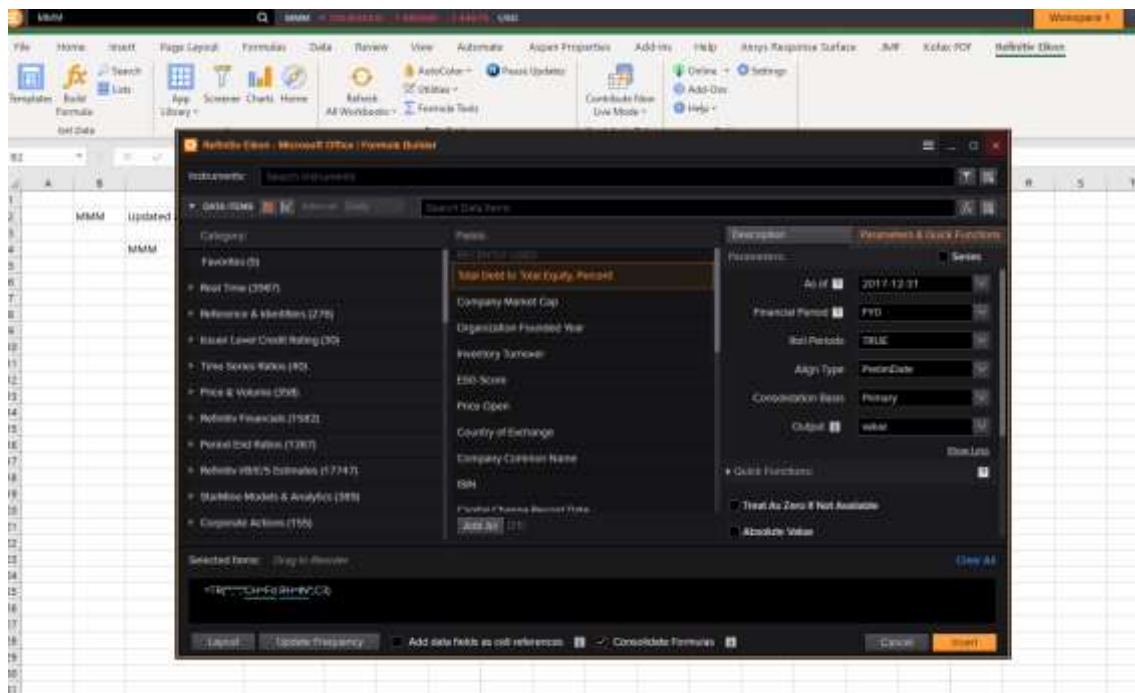


Figure A.3-3 Debt ratio

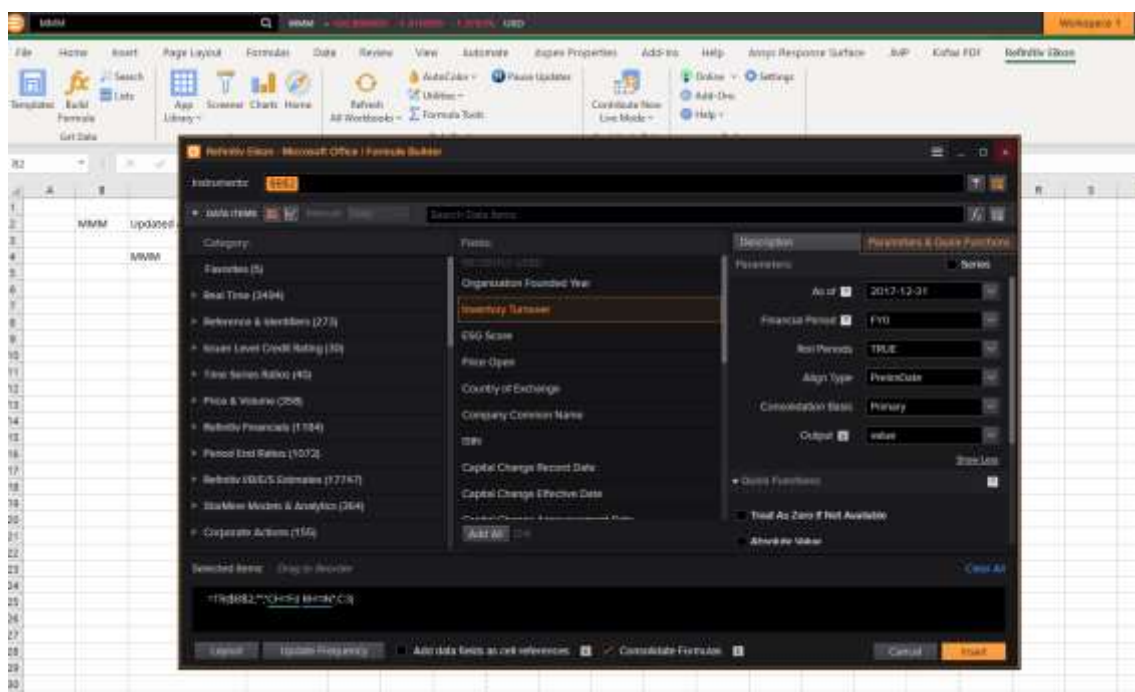


Figure A.3-4 Power over suppliers

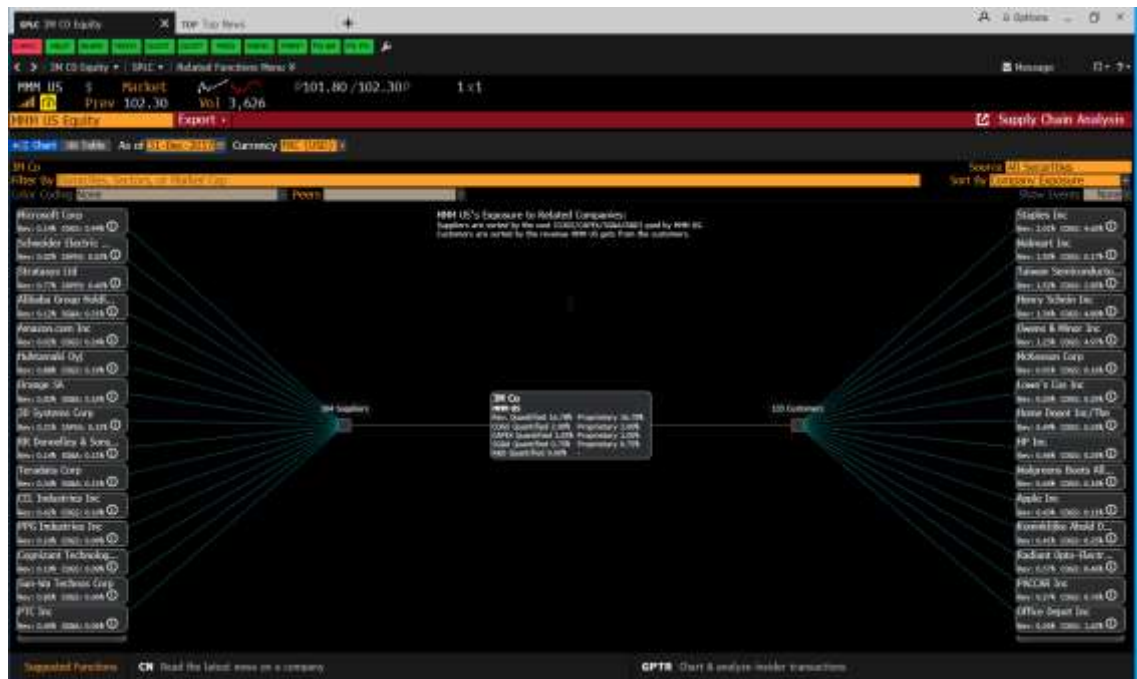


Figure A.3-5 Suppliers concentration

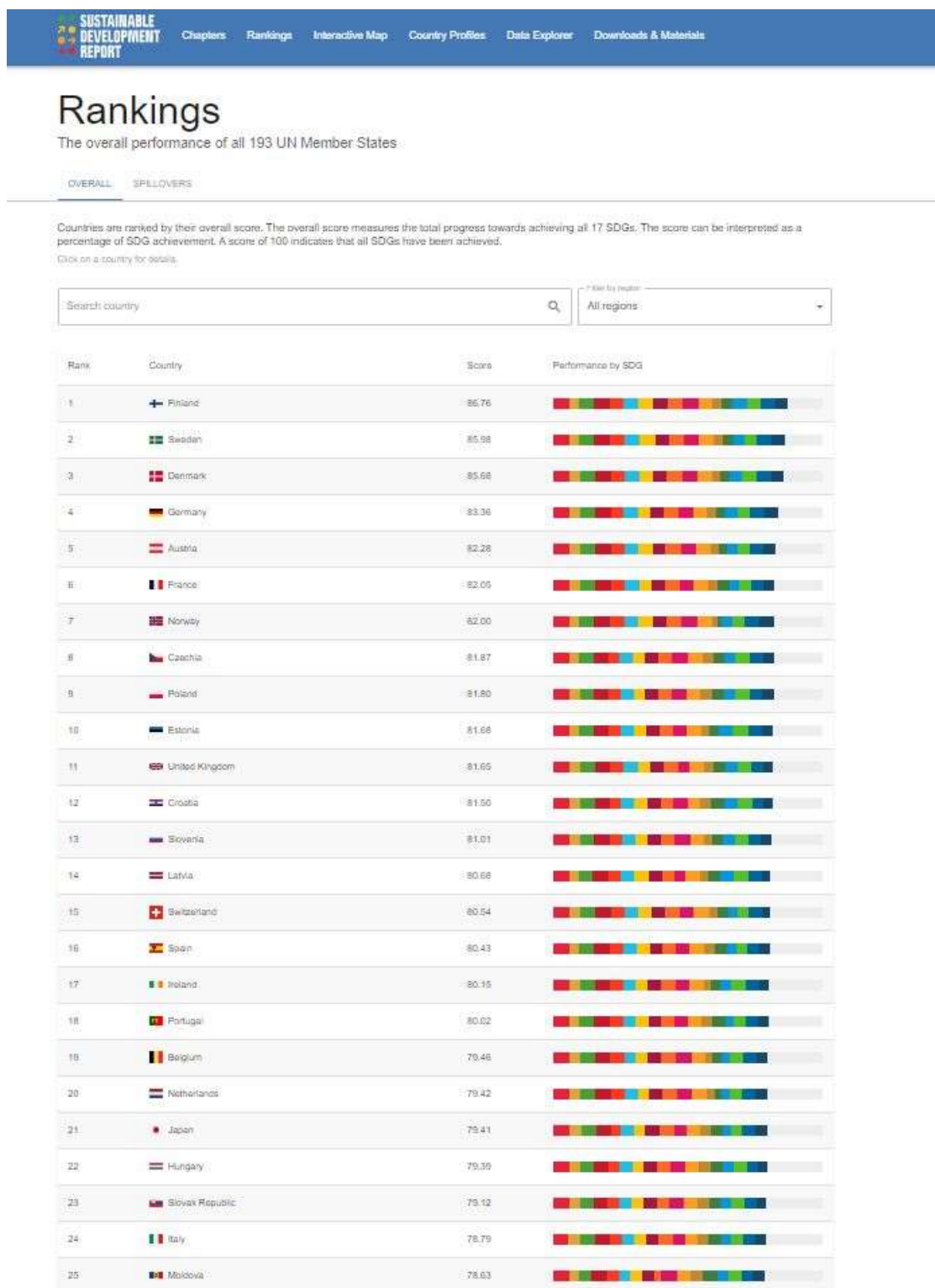


Figure A.3-6 Country

Appendix B Details of statistical analysis method

This study adopted the Ordinary Least Square (OLS) analysis as the method of analysis and the reason for choosing it is stated in the Table B-1. Before choosing this method, this study also considered several methods of analysis, i.e. lasso, stepwise, negative binomial and survey. More specifically, some methods, e.g. lasso and stepwise are suggested to solve the multicollinearity issue, while negative binomial and survey have been adopted before in the similar strand of research. Given this, Table B-1 provided reasons for not choosing those methods of analysis.

Table B-1 Method of analysis selection

Method of analysis	Reasons for choosing	Reasons for not choosing
Ordinary least square (OLS) analysis	1. Best linear unbiased estimator under the Gauss-Markov theorem 2. Suitable for those studies that have cross-sectional data in nature.	
Lasso analysis		Although Lasso could help minimize the prediction errors or solve the multicollenarity issues, the coefficients chosen is not appropriate for the full model
Stepwise analysis		Stepwise could help solve the multicollenarity issue as it aims to find the optimal subset of independent variables. However, the model would lose some important variables when it is doing the optimisation process.
Negative binomial analysis		Although this method has been adopted in previous scholar's research in investigating the influence of network structure and firm performance, it is only for modelling count variables.

Survey		Survey data may have the issue of low/non-response rate. For the number of firms having sustainability data in this study is limited, using survey data may cause the sample size further reduced and biased.
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