THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Reducing transport-related climate impacts within upstream supply chains: Challenges and opportunities for buying firms

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Abstract

This thesis deals with how buying firms can reduce transport-related climate impacts within their upstream supply chains. While transport is a major contributor to CO_2 emissions, upstream emissions, i.e. those embedded in purchased goods and transport, are often overlooked due to limited visibility and control. In line with this, the aim of this thesis is to explore how buying firms can reduce the transport-related climate impacts from their upstream supply chains and the main challenges and opportunities in doing so.

Theoretically the thesis is grounded in the Industrial Network Approach. Furthermore, it takes a starting point in the Transport Service Triad to explore the embeddedness of transport activities in supply networks and the role of purchasing in managing the transport demand to reduce CO_2 emissions.

A qualitative single case study approach is used, focusing on a Focal Manufacturing Company and its efforts to reduce the transport emissions embedded in their upstream supply chains. Furthermore, a literature review was conducted to get an overview of previous research in the area.

The thesis identifies key challenges and opportunities for emission reductions, including aspects such as supplier locations, lead time requirements, production methods, transport modes, and vehicle and fuel choices. The findings highlight the importance of reconfiguring supply networks, fostering collaboration with suppliers and transport service providers, and integrating sustainability in purchasing decisions and strategies.

The thesis contributes to the theoretical understanding of how transport activities are embedded in supply networks and offers practical insights for buying firms aiming to decarbonize their upstream supply chains.

Keywords: transport-related climate impacts, freight transport, upstream emissions, industrial network approach, transport service triad, supply networks, sustainability.

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List of abbreviations

AI: Artificial Intelligence

AM: Additive Manufacturing

CM: Conventional Manufacturing

CO_2: Carbon Dioxide

CSRD: Corporate Sustainability Reporting Directive

EC: European Commission

ERP: Enterprise Resource Planning

ESR: Effort Sharing Regulation

ETS: Emissions Trading System

EU: European Union

FMC: Focal manufacturing company

GHG: Greenhouse Gas

INA: Industrial Network Approach

IoT: Internet of Things

JIT: Just-In-Time

PSM: Purchasing and Supply Management

R&D: Research and Development

SCM: Supply Chain Management

SLDM: Supply Location Decision Making

TMS: Transport Management System

TST: Transport Service Triad

1. Introduction

This thesis deals with reducing transport-related climate impacts. The focus of the study is on how buying firms can reduce transport-related climate impacts in their upstream supply chains.

To effectively address how buying firms can reduce transport-related impacts in their upstream supply chains, it is important to situate the study within a broader context. Understanding the problem background, as well as an introduction to the research area and theoretical starting points of this study, provides a foundation upon which to interpret the relevance and applicability of the study's conclusions. Therefore, the following sections elaborate on these dimensions, offering insights into why the topic is timely and relevant.

This chapter starts by providing the background and relevance of the research. This is followed by the aim and research questions, and the chapter ends with the outline of the thesis.

1.1 Problem background and relevance

In their 2023 report, the Intergovernmental Panel on Climate Change (IPCC, 2023, p. 24) reiterated that 'Climate change is a threat to human well-being and planetary health (very high confidence). There is a rapidly closing window of opportunity to ensure a liveable and sustainable future for all (very high confidence)' (ibid). The IPCC report states that the transport sector plays a crucial role in reducing climate impacts and emphasises several key points regarding the importance of the sector in mitigating climate change (ibid). The sector is one of the largest contributors to global CO_2 emissions.[1] Emissions from the transport sector have been growing, driven by increasing demand for mobility and transport (ibid). This makes it a critical target for emission reduction efforts, and addressing emissions in this sector is essential for meeting global climate goals.

According to the International Energy Agency (IEA, 2022), transport is responsible for 24 per cent of direct CO_2 emissions, with 75 per cent of these emissions being produced by road vehicles. IEA tracking shows that the sector's high reliance on fossil fuels is

[1] CO_2 is the greenhouse gas (GHG) that is emitted the most. It accounts for approximately 80 per cent of the greenhouse gases in Europe. In this study CO_2 is used interchangeably with GHG.

the highest of any sector. If the current scenario persists, transport could become the most carbon-intensive sector (Greene, 2019). To follow the Net Zero Scenario, which limits global warming to 1.5 °C, reaching net zero CO_2 emissions around 2050, the emissions from the transport sector need to be reduced by about 20 per cent, a fall of approximately 3 per cent per year to 2030, which is equals to less than 6 Gt CO_2 by 2030 (IEA, 2022), as seen in Figure 1.

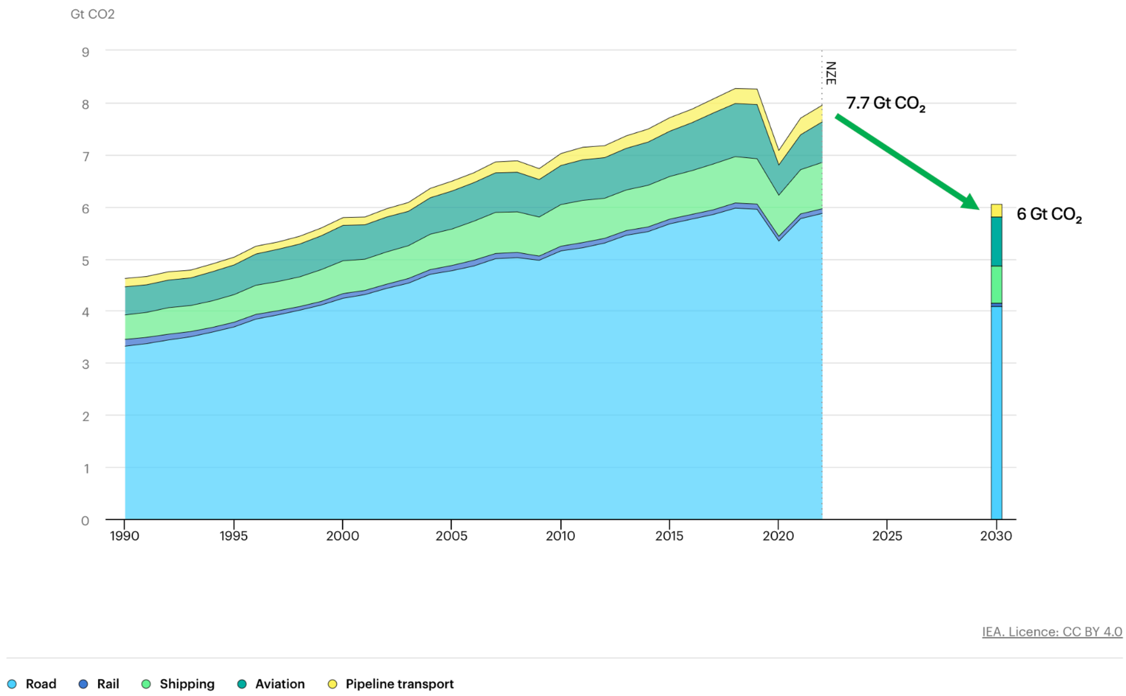

Figure 1. Modified from Global CO_2 emissions from transport by sub-sector in the Net Zero Scenario, 2000-2030[2].

The IPCC 2023 report concludes that, in transport, it is possible to reduce CO_2 emissions from, for example, shipping, aviation, and heavy-duty land transport with sustainable biofuels and low-emission hydrogen. However, all of these approaches require improved production processes and cost reductions (ibid). The production costs of sustainable fuels are still significantly higher than fossil fuels. An assessment of the potential of sustainable fuels in transport concluded that the high costs of sustainable fuels are driven by factors such as energy-intensive production processes, which means that the shift to sustainable fuels requires a considerable increase in energy efficiency (Trinomics, 2023).

[2] Change consists of highlighting the CO_2 emissions reductions needed to reach net zero CO_2 emissions. Source: IEA (2023), Global CO_2 emissions from transport by sub-sector in the Net Zero Scenario.

The growth of road transport is a persisting environmental burden. Freight transport makes up 40 per cent to 50 per cent of the energy used for all transport activities. In most economies, road transport is responsible for 80 per cent of the energy consumed domestically (Transport Geography, 2023). This means that road transport plays a major role in the overall energy consumption of transport.

Transport demand in Europe increased by 22 per cent between 2019 and 2020 (European Environment Agency, 2024). The Transport & Environment (2024) stated that in 2022 transport accounted for 29 per cent of all the European Union (henceforth referred to as EU) emissions. While emissions from other sectors have decreased by 38 per cent since 1990, transport emissions have increased by 25 per cent (Transport & Environment, 2024). Fuelled by rising freight activity and insufficient regulation, emissions from heavy-duty vehicles have also surged significantly since 1990 (ibid). This makes the task of decarbonising the sector more challenging and more urgent (ibid).

In a study of four global transport decarbonisation strategies for 2050, de Blas et al. (2020) highlighted that modal shifts towards electrification options contribute to significant reduction of emissions. However, it is very hard to electrify heavy vehicle transport and air and water transport, which makes it challenging to reduce their GHG emissions (ibid). The authors concluded that very strong policies are needed to reduce 80 per cent of GHG in transport by 2050, compared to emissions in 2020. Out of the four strategies, only the one combining significant reduction of transport demand, air freight in particular, major shift towards light vehicles and key mineral recycling (for example, lithium and magnesium are required for a transition for sustainable mobility but have limited availability) can accomplish the targets of reductions of GHG emissions (ibid). Korkmaz et al. (2021) also pointed out that decarbonising transport is challenging, due to factors such as the sector being heavily reliant on fossil fuels and other technological constraints. Road transport is 95 per cent dependent on petroleum products and air transport, and waterborne transport relies almost completely on petroleum products. Hence, most transport technologies still use liquid fossil fuels (ibid).

There is a growing demand for sustainable transport solutions (Elassy et al., 2024). Aligned with this, and concerned with the current transport scenario, the European Commission (henceforth referred to as EC) has proposed an initiative that aims to make transport in the EU more efficient and sustainable. This initiative is aligned with the goal of reducing transport emissions by 90 per cent by 2050, compared to 1990 levels. as outlined in the European Green Deal. Key measures in the initiative include enhancing rail infrastructure management, introducing new incentives for using low-emission trucks, and establishing a standardised methodology for companies in the freight sector to calculate their greenhouse gas (henceforth referred to as GHG) emissions (European Commission, n.d.a).

Another EC initiative is the Effort Sharing Regulation (henceforth referred to as ESR), which is part of a set of policies and measures that aims to reduce emissions by a minimum of 55 per cent from 2021 to 2030 compared to 1990 levels (European Commission, n.d.b.). ESR targets vary between Member States, according to their gross domestic product (GDP) per capita and their national targets. ESR is related to emissions from sectors that together account for almost 60 per cent of the EU emissions. These sectors are domestic transport (excluding aviation), buildings, agriculture, small industry, and waste (ibid). Transport is the sector with the highest intended reduction target, with 50 per cent of a planned additional reduction by 2030 (LIFE Unify, 2022).

The Greenhouse Gas Protocol (2020) allocates GHG emissions into three scopes. Scope 1 emissions correspond to direct emissions from owned or controlled sources. Scope 2 emissions correspond to indirect emissions from the generation of purchased energy. Scope 3 emissions are all upstream and downstream indirect emissions (not part of Scope 2) that take place in the supply chain of a company but are not generated by the reporting company. Scope 3 commonly represents a company's largest GHG impacts and comprises emissions from outsourced transport (Ellram et al., 2022). Furthermore, the Greenhouse Gas Protocol (2020) divides CO_2 emissions into upstream or downstream sources. Upstream emissions come from the production of the company's products or services. There are eight[3] types of upstream emissions, one of which is transport. Downstream emissions are the emissions generated from the transport of finished products to consumers and for the use or disposal of a company's products or services.

As part of the 2023 revisions of the EU Emissions Trading System (henceforth referred to as ETS) Directive, a new directive called ETS2 CO_2 was created to address emissions from fuel combustion in buildings, road transport, and small industries not covered by the original EU ETS. The ETS2 will become fully operational in 2027 and will acta as a cap-and-trade system targeting fuel suppliers rather than end users, with the goal of reducing emissions in these sectors by 42 per cent by 2030 compared to 2005 levels (European Commission, n.d.c.). The key impacts of the ETS2 on transport include cost increases, as the introduction of a carbon price on fuel will lead to higher fuel costs for

[3] (1) Purchased goods and services, (2) capital goods, (3) fuel- and energy-related activities, (4) upstream transport and distribution, (5) waste generated in operations, (6) business travel, (7) employee commuting and (8) upstream leased assets.

fuel suppliers that will pass it forward along the supply chain (Freight Perspectives, 2023); operational restructuring, as the directive is expected to create a need for a strategic evaluation of fleets, including the adoption of alternative fuels and zero-emission vehicles (Bakker et al., 2025); and technological adoption and modal shift as, in the medium and long term, the directive incentivises the adoption of low and zero emission technologies as well as changes in routing and transport modes to minimise emissions (Haywood & Jakob, 2023; Flodén et al., 2024).

All these regulations that aim to reduce transport-related emissions will impact manufacturing companies, making the cost of transport emissions higher. Consequently, how companies can reduce these emissions will become a priority.

The societal and policy relevance of this study lies in highlighting the importance of reducing transport-related climate impacts for the achievement of the main global climate targets, such as the Paris Agreement and the Sustainable Development Goals. Through examining ways to reduce emissions, this study highlights the potential for firms to decarbonise transport and provides insights to support the achievement of these targets, contributing to a low-carbon society and policy frameworks aimed at sustainable transport.

1.2 Introduction to the research area

Reducing the climate impact of transport at the firm level is a complex and multifaceted challenge. Firms face a variety of challenges in their efforts to decrease emissions from transport, particularly when considering the emissions generated through their purchasing behaviour.

Another factor when firms aim to reduce the climate impact of transport-related upstream CO_2 emissions is the fact that buying firms are not always aware of the transport activities that their operations generate. In other words, buying firms cannot always be sure where a supplier is sourcing or sending materials from, nor the transport route, transport mode or fuel of its choice (Choi et. al., 2021). More firms worldwide are outsourcing their logistics to transport service providers and as these transport emissions are outside of their direct control, many firms do not take actions to reduce them (Abbasi et al., 2024). This is due to the lack of visibility of the transport activities included as part of the offerings in the purchasing of goods and because firms often lack access to reliable emissions data from transport providers. Hence, it becomes difficult for the buying firms to know how their purchasing behaviour affects the transport activities embedded in their supply chains and what could be done to make their supply chains more sustainable.

In recent decades, purchasing and supply management (henceforth referred to as PSM) has experienced important developments driven by trends such as outsourcing, offshoring, and globalisation. As a result, supply networks have become more geographically distributed, impacting on the length and complexity of supply chains (Gadde et al., 2010; Kazancoglu et al., 2024), increasing the importance of and reliance on suppliers (Gadde et al., 2010; Araujo et al., 2016; Allah, 2023) and intensifying transport activity (McKinnon, 2010; Podocin & Ovsiannikova, 2021). However, PSM has also become challenged by the growing emphasis on sustainability and the advent of digital transformation (Di Mauro et al., 2024).

One of the most critical consequences of these changes is the environmental impact associated with transport. According to McKinnon (2010), the primary factors driving transport-related CO_2 emissions in global supply chains are the increasing length of supply chains and thus increasing transport activity together with the prevalent use of carbon-intense transport modes. More recently, this assessment was supported by the European Environment Agency (EEA, 2022), which stated that the increase in transport demand is the main factor behind the growth of transport-related CO_2 emissions and that the use of trucks has grown. This trajectory is expected to grow, as the International Council on Clean Transportation (ICCT, 2025) projects transport emissions to peak as early as 2025 and that road transport, primarily trucks, will remain the dominant and growing source of transport emissions.

Considering these persistent and projected emission trends, it is important to understand the broader challenges associated with the achievement of environmental sustainability within transport. In a systematic literature review, Ellram and Murfield (2017) discussed challenges to sustainability in general and to transport in particular. Regarding broader sustainability challenges, they pointed out the barriers firms face to integrate sustainability into their operations. These include high costs, need for additional resources, and the trade-offs between their priorities and environmental goals. When focusing on transport-related sustainability challenges, the authors highlighted challenges such as the complexities associated with modal shifts, and difficulties in determining baseline data for emissions and environmental impacts. The authors also noted that environmental sustainability in transport has historically received limited attention within broader SCM research. Their results show that transport is often treated as a secondary element rather than a core component of sustainable supply chain strategies, despite freight accounting for 8 per cent of global CO_2 emissions and 30 per cent of transport-related emissions.

Nonetheless, the efforts to reduce transport-related emissions can be organised around five key areas: (1) reducing transport demand, (2) increasing transport mode efficiency, (3) promoting modal shifts, (4) adopting lower-carbon fuels, and (5) advancing lower-carbon vehicle technologies (Nordic Council of Ministers, 2018). McKinnon (2018) also examined five categories that contain a range of technological, managerial, operational and regulatory options for decarbonising logistics that match the key areas described above. They are: (1) restrain the growth in demand for transport, (2) make more use of lower carbon transport modes, (3) optimise vehicle loading, (4) improve energy efficiency, and (5) foster renewable energy use. Each area presents unique challenges, particularly as firms need to balance environmental goals with operational, financial, and regulatory constraints. Both the Nordic Council of Ministers and McKinnon's five key areas/categories to reduce transport-related emissions have been reiterated by the Intergovernmental Panel on Climate Change (IPCC) through its 'Avoid-Shift-Improve' (ASI) framework for transport emission reductions strategies. 'Avoid' strategies aim to reduce total vehicle travel, 'Shift' strategies aim at modal shifts from higher-emitting to lower-emitting modes, and 'Improve' strategies to reduce emission rates per-kilometre (IPCC, 2022). The link between the efforts to reduce transport-related emissions, as defined by the Nordic Council of Ministers, McKinnon and the IPCC, are summarised in Table 1.

First, reducing transport demand is on the top of these challenges, as transport demand is expected to increase. A recent study using transport models to estimate future global transport demand until the year of 2050 (Tjandra et al., 2024) estimated that from 2020 to 2050 transport demand will grow by 200 per cent. McKinnon (2018) suggested that transport demand can be reduced by actions such as reconfiguring supply chains, designing transport routes more efficiently, turning some production and distribution operations more local, adopting additive manufacturing (henceforth referred to as AM) and the move to a circular economy within closed loop supply chains.

Second, achieving transport mode efficiency refers to improving the performance of vehicles or logistics systems to reduce emissions per unit of transport service (for example, ton-kilometres). McKinnon (2018) stated that transport mode efficiency could be achieved through online platforms for the trading of freight capacity and increased disposition by companies to share their vehicle capacity. Other authors have mentioned that firms can achieve transport mode efficiency using vehicles that have a better design, optimised routing, enhanced fleet management, and improved fuel efficiency (Chen et al., 2023; Wang et al., 2024). Among the challenges to increase transport mode efficiency at the firm level are (1) the costs of investments, as upgrading fleets to more efficient models could require substantial capital (Rehmatulla & Taylor, 2023); (2)

closing technological innovation gaps, as the pace of innovation may not be fast enough to improve the efficiency of the comprehensive transport network (Xia , 2023); and (3) operational disruptions, since the implementation of efficiency measures may require changes in how firms operate, such as altering delivery schedules or changing supply chain logistics, which can disrupt their operations or reduce their flexibility (Lordiek & Corman, 2021).

Third, promoting modal shifts means switching from higher-emission transport modes to lower-emission alternatives. Firms can achieve this by switching, for example, from air to sea. McKinnon (2018) also suggested internalising the environmental costs of transport in higher taxes. At the firm level, challenges might include infrastructure limitations, as firms could face challenges with inadequate or underdeveloped infrastructure for lower-carbon transport modes (Dimitriadou et al., 2023), such as insufficient rail networks or poorly connected intermodal hubs. Another challenge could be a lack of flexibility, which under some circumstances (such as an urgent delivery time) may not be feasible. Cost and time considerations also represent a challenge, as shifting to lower emitting modes like rail or sea may be more environmentally friendly but can increase costs and delivery times. In highly competitive sectors where customers demand just-in-time (henceforth referred to as JIT) delivery, justifying these shifts could represent a struggle (Dimitriadou et al., 2023).

Fourth, adopting lower-carbon fuels refers to transitioning from high-carbon-content fuels to fuels with lower carbon content, such as biofuels, hydrogen, or electricity. This creates challenges for firms given that the availability and scalability of low-carbon fuels such as hydrogen or biofuel are still limited in many regions. Firms can have difficulties to secure a reliable supply, and the cost of fuel transition is also an issue (Neagoe et al., 2024), as lower-carbon fuels are often more expensive than traditional fossil fuels. This can be a significant barrier for cost-sensitive industries such as logistics (ibid).

Fifth, advancing the use of lower-carbon vehicle technologies means adopting electric vehicles, hydrogen fuel cell vehicles or hybrid technologies. This is challenging for firms because it requires substantial upfront investment in new vehicles (Neagoe et al., 2024), which can be too expensive for firms operating on tight margins and the need for infrastructure development (Dimitriadou et al., 2023), including charging infrastructure for electric vehicles and refuelling infrastructure for hydrogen vehicles. The current infrastructure gap makes it challenging for firms to rely on these technologies for long-distance or high-volume transport (ibid). Apart from the above-mentioned technological aspects, Raoofi et al. (2024) also highlighted that electrification of transport should contemplate a higher system level, considering how the system is affected by different actions or decisions. By considering three system layers (the supply chain layer, the transport layer and the infrastructure layer), they developed a conceptual model to provide a holistic picture of the system that can help to understand the electrification transition.

Table 1 sums up the different approaches that firms can apply to minimise the challenges to reduce their transport emissions, showing how they relate to each other.

ASI Framework (2022)	Nordic Council of Ministers (2018)	McKinnon (2018)	Focus
Avoid	Reduce transport demand	Restrain growth in transport demand	Reduce total vehicle kilometres travelled by minimising unnecessary transport activities
Shift	Promote modal shifts	Make more use of lower carbon transport modes	Shift freight from high emission modes to more sustainable modes
Improve	Increase transport mode efficiency	Optimise vehicle loading	Enhance operational efficiency to reduce emissions per unit of freight
	Advance lower carbon vehicle technologies	Improve energy efficiency	Adopt technologies that reduce energy consumption per kilometre
	Adopt lower-carbon fuels	Foster renewable energy use	Replace fossil fuels with renewable or low carbon alternatives

Table 1. Summary of different approaches firms can use to reduce their transport emissions.

In several industries, companies have set emission-reduction goals and targets for their Scope 3 emissions. Between 2017 and 2021, the number of companies that agreed to science-based targets increased at an annual rate of 119 per cent, of which 96 per cent have targets covering Scope 3 emissions (McKinsey & Company, 2022). Since 2022, more than 1,400 companies have set so-called science-based targets. Science-based targets give businesses a well-defined way to cut their GHG emissions. If a target aligns with the most recent findings in climate science to achieve the Paris Agreement's main objective of keeping global warming to 1.5°C over pre-industrial levels, it is referred to as 'science-based' (Science Based Targets Initiative, 2022). According to the Science

Based Targets Initiative (SBTi), science-based targets play a crucial role in mitigating the worst effects of climate change while ensuring the sustainable growth of businesses in the future, as they drive businesses to innovate and adopt new technologies and practices, allowing businesses to commit to reducing their GHG emissions across their operations and value chains. Additionally, they involve regular reporting, promoting accountability and transparency (Science Based Targets Initiative, 2022).

Reporting transport-related CO_2 emissions is another important step towards reducing emissions. When firms report on them, it helps explain their origin, define reduction targets and how to achieve these targets. However, reporting emissions from transport is a complex matter and constitutes a challenge for many companies. The Greenhouse Gas Protocol (2020) presents standards and guidance that are designed to provide a framework for businesses to measure and report their GHG emissions, helping them to achieve their emissions reductions targets. According to the World Wildlife Fund, by 2021, even though 92 per cent of the Fortune 500 companies have adopted the standards defined by the Greenhouse Gas Protocol (Greenhouse Gas Protocol, 2020), not all companies currently report on transport emissions. Only 91 (nearly 20 per cent) Fortune 500 companies have a climate goal that covers indirect emissions (Scope 3) across their supply chains (WWF, 2021). More recent data shows the number of Fortune 500 companies reporting on upstream transport and distribution (Scope 3 category) grew from 210 in 2021 to 284 in 2023 (The Center for Audit Quality, 2025).

Another important directive regarding reporting is the Corporate Sustainability Reporting Directive (henceforth referred to as CSRD), announced by the EC in 2021. This directive is in line with the commitment made under the European Green Deal. The CSRD will represent a significant increase for the reporting requirements on companies' efforts to expand the sustainability information for users. The number of companies subject to the EU sustainability reporting requirements will also grow (KPMG, n.d.).

The results of this study can contribute to bring awareness and visibility of practical actions that managers can focus on to help their firms achieve their targets/goals regarding reducing their transport-related climate impacts from their upstream supply chain.

1.3 Theoretical starting points

Supply chain management (henceforth referred to as SCM) decisions usually do not take transport activities into consideration, despite their critical role and associated environmental impacts. Browne et al. (2023) argued that transport activities are often neglected or treated as a consequence of other supply chain decisions rather than as an integral part of supply chains. Hence, transport has mainly been treated as a derived demand stemming from other decisions. However, and in line with Hesse and Rodrigue (2004), transport is not only a derived demand but also integrated (or embedded) in supply chains. This means that if a firm wants to approach the effects of transport activities in their supply chains they need to consider these in relation to other activities in the supply chain and how these are organised.

The Transport Service Triad (henceforth referred to as TST) provides a key unit of analysis to capture the interdependence between the relationships between the actors that set the conditions for transport: the buyer of goods, the seller of goods, and the seller of transport services (Eriksson, 2019). The TST is composed by two connected relationships. One relationship deals with the exchange of goods between the buyer and seller. The other relationship deals with the exchange of the transport service between the buyer of transport services and the seller of transport services. The buyer of transport services can be either the buyer or the seller of goods. The triadic perspective highlights how the decisions and interaction between these actors impact on the transport activities, which also determine their environmental impacts (Eriksson, 2019). Eriksson et al. (2022) underlined that collaboration among the TST actors is a key to reducing environmental impacts. The TST highlights how supply chain decisions generate transport demand, and how those decisions are vital for reducing the climate impacts of transport, pointing to the relevance of exploring this further.

The Industrial Network Approach (henceforth referred to INA) provides a theoretical lens that helps to explain the embeddedness and interdependencies of transport activities in supply networks. The INA conceptualises business markets as complex networks of interconnected actors, resources and activities whose relationships are characterised by interdependence, connectedness and embeddedness (Håkansson and Snehota, 1995; Ford et al., 2003). From this viewpoint, transport is understood as a focal activity that is linked to other supply network activities, resources and actors. These interconnected relationships create both challenges and opportunities for managing and reducing transport-related climate impacts through the coordinated action across the network.

Given these theoretical insights, the present thesis focuses on exploring how the embedded and interdependent nature of transport in supply networks impacts on how buying firms can address the challenge of reducing their upstream transport emissions. It further investigates how purchasing strategies can contribute to address the challenge.

1.4 Aim and research questions

To reduce the climate impact from transport in their upstream supply networks, firms must develop and implement suitable purchasing strategies. However, in order to develop and implement such strategies, it is necessary to address several challenges. One considerable challenge is the complexity of supply networks, where coordination across multiple supplier relationships and the embeddedness of transport activities makes it challenging for buying firms to acquire knowledge about the transport generated by their purchasing behaviour.

The aim of this thesis is to explore how buying firms can reduce the transport-related climate impacts from their upstream supply chains and the main challenges and opportunities in doing so.

To achieve the research purpose of understanding how buying firms can reduce the transport-related climate impacts within their upstream supply chains, two broad research questions are formulated:

RQ1: How can buying firms reduce transport emissions in their upstream supply chains?

RQ2: What are the main challenges buying firms face in their attempts to reduce transport-related climate impacts within their upstream supply chain?

1.5 Outline of the thesis

This thesis consists of seven chapters. Chapter 1, this introductory chapter, is followed by Chapter 2, which discusses previous research on reducing transport-related emissions in upstream supply chains. Chapter 3 outlines the frame of reference and problem discussion, before Chapter 4 outlines the methodological considerations of the study. Chapter 5 introduces the case company together with the goals and conditions for their efforts to reduce their upstream emissions. Chapter 6 contains the analysis of the study, and Chapter 7 presents the concluding discussion of the study, together with ideas for further research.

2. Previous research on reducing transport-related emissions in upstream supply chains

Given the substantial contribution of transport to overall GHG emissions, it is imperative for buying firms to adopt effective strategies to mitigate transport-related emissions within their upstream supply chains. The literature identifies five key areas to address these emissions. Each of these areas has a direct and indirect impact on upstream supply chain emissions: (1) selecting suppliers in view of their geographic location can reduce transport distances (Böge, 1995; McKinnon, 2010; Sarıoğl, 2023) (2) reconsidering strict lead time requirements, which necessitate more carbon-intensive transport modes (Rogerson, 2017; Li et al., 2019; Lei, 2022); (3) working on production methods improvements can reduce the transport demand (Gibson et al., 2021; Zhang et al., 2022); (4) making informed choices of transport mode, as these are key determinants of transport emissions (Björk et al., 2023; Girteka, 2024); and (5) using vehicles and fuels with lower carbon emissions (Ferre & Thomé, 2023; Koh et al., 2023).

The next sections provide an overview of previous research in the five areas, linking to relevant literature to explain their potential for reducing transport-related emissions in supply chains.

2.1 Supplier base and locations

The influence of supplier location on transport-related emissions has been increasingly recognised in both academia and industry. Drawing on in-depth interviews with 12 firms, Ellram et al. (2022) observed that although decisions concerning the supplier base, including supplier location, impact emissions in supply chains, most firms have yet to take responsibility for freight emissions in their supply chains. Even though the current reporting standards do not require firms to report on indirect transport-related emissions in upstream supply chains firms that do so could recognise their responsibility on these emissions, as they result from the firms' decisions (ibid).

The relationship between supplier location and transport-related CO_2 emissions is well established in the literature. Early on, based on a case study of the transport activities generated by the supply chain of a simple product, Böge (1995) argued that regional sourcing can reduce transport emissions. Similarly, McKinnon (2010) recognised that buying from onshore instead of offshore suppliers supports the use of more environmentally friendly transport modes and contributes to a reduction in the need for transport. Benjaafar et al. (2013) reinforced this by suggesting that firms' sourcing decisions impact on their transport-related emissions. By adopting practices such as using suppliers that entail less transport, buying firms can reduce their transport-related emissions (ibid). According to Benjaafar et al. (2013), this is a double win, as these operational changes can lead to significant reductions in emissions and also reduce the transport costs (ibid).

Given that longer transport distances lead to higher CO_2 emissions, supplier location becomes a crucial factor for sustainable supplier selection (Kumar et al., 2014). More recently, through the development of a supply location decision-making (SLDM) approach, Sirilertsuwan et al. (2020) created a holistic method to enhance multi-tier supply chain sustainability. This approach highlights the critical role of supplier location choices in mitigating emissions and enhancing sustainability across supply networks.

Empirical evidence also supports the environmental benefits of sourcing from geographically closer suppliers. In a paper examining the impact of nearshoring on CO_2 emissions in the textile industry, Sarıoğl (2023) found that shifting to geographically closer suppliers can allow significant reduction of inbound transport emissions. That study showed that there was a projected reduction of over 20,000 tons of CO_2 over a period of 10 years for the case analysed.

Another aspect related to strategic supplier selection is the design of the supplier base. Gadde et al. (2010) highlighted that the supplier base of a buying firm is a significant asset and decisions regarding it, such as collaboration, location, and consolidation, are critical issues to deal with in view of the complexity of such supplier structures. This complexity is mainly due to some of the supplier base characteristics; namely, large numbers of suppliers, large variety of goods and services, its significant impact on the buyer's performance and the fact that it represents a unique set of resources.

Considering the central role that supplier base characteristics play in the efficiency and effectiveness on the supply side of a buying firm, the management of these relationships is critical. Ellram and Tate (2024) highlighted that suppliers are responsible for a relevant share of organisations' total emissions, hence the engagement with suppliers becomes a necessity to reduce CO_2 emissions. Eggert and Hartmann (2021) stated that firms that engage in more advanced practices in supplier management and environmental purchasing are more likely to reach higher supply chain environmental performance, which is directly reflected by reductions in GHG emissions. The authors stated that 'Collaboration between buyers and suppliers supports shared environmental planning, goal setting, and assists in lower negative environmental impacts including greenhouse gas emissions' (Eggert & Hartmann, 2021, p.4). Collaborative planning between buying firms and their suppliers can facilitate route optimisation, shipment consolidation and shared logistic planning (Eggert & Hartmann, 2021).

Despite these advantages, the strategic selection of suppliers remains a complex challenge in supply chain design. Katiraee et al. (2024) reinforced the argument that supply chain sustainability is deeply affected by supplier location. However, they also noted that the strategic selection of suppliers is one of the key challenges in supply chain design, together with balancing environmental and economic objectives, managing supply chain flexibility and resilience, regulatory compliance, and transport and logistics environmental impacts.

To conclude, the literature indicates that supplier location and the design of the supplier base are critical areas to consider when working to reduce the transport-related emissions. To achieve these benefits, buying firms must integrate environmental considerations into their supplier selection processes and work to overcome the challenges associated with these changes.

2.2 Lead time requirements

The design of supply chains plays a key role in reducing transport-related CO_2 emissions (Elhedhli & Merrick, 2012). A study by Lei (2022) introduced a framework for optimising supply chain networks that firms can use to reduce industrial carbon emissions from transport and other carbon-intensive activities such as production processes, packaging, and waste management The study emphasised the importance of supply chain network design for reducing emissions. This involves several important decisions, such as supplier location (as discussed in Section 2.1) and lead time requirements. The configuration of lead times within supply chain networks not only affects operational efficiency but also has environmental implications.

Short lead time requirements can trigger an increase in the use of emergency or accelerated shipping, usually resulting in the choice to use high emitting transport modes, specifically air freight (Arikan et al., 2014). Several studies have estimated that air freight emits up to 47 times more CO_2 per ton-mile than sea freight, making it a significant contributor to overall supply chain emissions (MIT, 2010; InTek Logistics, 2022). Consequently, the pressure to meet short delivery deadlines can significantly increase the carbon footprint of supply chains.

Conversely, reducing lead time variability making transport and delivery time more predictable and consistent offers several environmental benefits (Arikan et al., 2014).

The authors point out that reducing lead time variability not only lowers the need for emergency shipments, but also allows better vehicle utilisation and shipment consolidation, both of which reduce emissions.

Li et al. (2019) also explored how lead time requirements affect supply chain performance, including carbon emissions, with lead time being a major factor impacting supply chain sustainability. They concluded that increased lead time uncertainty can result in higher carbon emissions, due to increased transport demand and the use of more energy-intensive transport modes. Drawing on Hoen et al. (2012), Li et al. (2019) found that lead time directly affects transport-related carbon emissions. For instance, Hoen et al. (2012) found that although switching transport modes can trigger large emissions reductions, lead time variability will be the key factor, as it will define the transport mode choice.

The broader relevance of addressing lead time requirements to reduce transport emissions has also been recognised in industry reports. One of these reports, written by The World Economic Forum and Accenture (2009), for instance, examined 13 forms of decarbonising supply chains, the second-most effective of which is 'despeeding supply chains'. The report highlights that 'Speed in the supply chain is driven by factors such as lead times, deadlines and booking windows. This increases emissions – for example through switches to less efficient modes of transport, increases in the number of expedited orders, and increased vehicle and trip speeds' (The World Economic Forum & Accenture, 2009, p.17), and that 'easing lead times and delivery stipulations could lead to emission abatements through despeeding'(ibid).

On the same topic, McKinnon (2016) discussed the possible contributions of transport deceleration to decarbonise logistics. He categorised the opportunities that 'despeeding' – the process of reducing speed within the supply chain to achieve lower carbon emissions – creates to cut CO_2 emissions in three categories: (1) direct, 2) indirect and (3) consequential. He mentioned that there is clear evidence that slow operations for trucking and sea transport directly reduce CO_2 emissions; that sourcing locally could enable slow speed freight; and that some other measures, such as modal split or a switch to low carbon fuels, could lead to transport deceleration. However, he also remarked that deceleration should not be viewed as a generally applicable decarbonisation measure, because in some cases, such as for low carbon transport modes, incentivising acceleration could be the factor that would make them more competitive and broadly adopted. The relationship between lead time and transport speed, particularly slow steaming by sea, has also been the subject of previous research. Some authors have remarked that increased lead time is a direct result of slow steaming (Finnsgård et al., 2020). Others have highlighted that, in addition to reducing CO_2 emissions, slow speed also triggers a reduction in fuel consumption (Degiuli et al., 2021). The case study conducted by Finnsgård et al. (2020) showed that although slow steaming has the potential to reduce CO_2 emissions, it has mainly been adopted due to temporary reduced shipping volume, abundance of capacity, high fuel prices and low freight rates and, thus, if these conditions change, the use of slow steaming is expected to drop.

Rogerson (2017) noted that strict lead time requirements can negatively affect the load factor and length of the haul, which will influence fuel efficiency and transport emissions. She also pointed out that firms should consider how lead time impacts transport performance and emissions to avoid negative environmental impacts (ibid). Although shipment consolidation can have an impact on lead time, it can offer a potential trade-off as it may reduce the number of transport activities and consequently lower transport-related emissions. Suppliers that are located close to each other or have the same routes can collaborate to reduce transport emissions through the consolidation of shipments. Moreover, collaboration with transport service providers to consolidate shipments can contribute to the optimisation of deliveries, reducing transport and transport-related CO_2 emissions.

McKinnon (2010) discussed freight consolidation as one way in which logistics service providers can reduce the carbon intensity of the energy they use and increase the energy efficiency of their operations. Benjaafar et al. (2013) argued that determining the frequency of deliveries could be as important in reducing CO_2 emissions as the energy efficiency of the vehicles used to make these deliveries. They highlighted that many popular business practices, such as JIT manufacturing and lean production, are challenging in terms of reducing transport-related emissions because they trigger frequent deliveries, which can result in low fill rates, impacting on the transport carbon footprint of a firm. To address these challenges, improvement areas for carbon-intensive transport might include the adoption of consolidation of shipment loads and route optimisation for logistics (Lei, 2022). This is also supported by Kuśmińska-Fijałkowska et al. (2024), who acknowledged that combining multiple shipments into a single vehicle directly reduces transport-related CO_2 emissions, playing a key role in reducing transport-related emissions.

While a lot of research points to the benefits of consolidating shipments to reduce transport-related emissions, data from Eurostat (2021) indicates that around 20 per cent of road transport in the EU in 2020 operated empty, which contributes to inefficiencies and unnecessary emissions.

In summary, managing lead time requirements is important to reduce transport-related emissions. Flexible lead times enable more sustainable transport practices, such as slow steaming and shipment consolidation, while strict requirements usually trigger high emission transport modes. Hence, buying firms need to balance operational demands with environmental goals, integrating lead time considerations into broader supply chain decisions.

2.3 Production methods

Production methods may also impact on transport-related emissions; for example, how production processes are organised directly influences transport needs. Historically, the concept of decentralised production to minimise transport has been considered. Böge (1993, p.10) highlighted that:

‘To reduce distribution shipments fundamentally, there is the possibility to create decentralized or regional production structures. To reduce distances in transport processes from manufacturing to trade means in the end a reduction of transport costs for the manufacturer. The more decentralized the economy organizes its production structures the faster can the aim be achieved to create freight shipping in an environmentally sound and socially equitable way’.

This insight has become even more relevant in the context of recent technological advancements, especially with the rise of the use of AM and digital supply chain technologies.

More recent research (IEA, 2023; Wang et al., 2024; Forge, 2025) shows that even slight changes in conventional manufacturing (henceforth referred to as CM), such as sourcing locally (also discussed in Chapter 2.1) can reduce transport. Moreover, adopting decentralised production models can impact transport demand and, consequently, transport-related emissions (ibid.). The adoption of AM is one example of this trend, with the potential to create other sustainability advantages. AM can help buying firms reduce transport-related CO_2 emissions through two mechanisms. The first is by reconfiguring supply networks, reducing material types and minimising transport needs (Huang et al., 2013; Ford & Despeisse, 2016; Gibson et al., 2021), and the second is by enabling more localised production, closer to consumers, thus reducing transport distances (Chen et al., 2015; Kellens et al., 2017; Gibson et al., 2021).

The reconfiguration of supply networks with the use of AM is particularly relevant. By designing products with fewer components and materials, AM can potentially reduce the number of manufacturing steps and suppliers. Huang et al. (2013) and Ford and Despeisse (2016) noted that the introduction of AM can create simpler products and reduce supply chain complexity because products will be designed with fewer components, materials, actors, manufacturing stages and interactions. As a result, the scale of material flows is reduced, which impacts the configuration of the whole supply chain. Gibson et al. (2021) joined the discussion, arguing that AM enables reconfiguration of supply networks by reducing the number of materials, manufacturing processes and suppliers. Hence, according to these authors, supply network reconfiguration due to the introduction of AM has the potential to lower transport-related emissions.

Furthermore, the switch from centralised to decentralised production, based on the use of AM or other digital technologies, has the potential to reduce transport distances and corresponding CO_2 emissions. Chen et al. (2015) argued that switching from centralised to decentralised production means that transport distances can be reduced, resulting in fewer transport-related CO_2 emissions. Kellens et al. (2017) also discussed the potential of AM to facilitate the reduction of transport-related CO_2 emissions through decentralised production. Components can be produced closer to clients, which will lower transport distances and potentially reduce CO_2 emissions. This is also reinforced by Gibson et al. (2021) when they discussed the motivations for adopting AM. They mentioned that AM fosters the ability to produce parts closer to the end user, which reduces transport requirements and related CO_2 emissions.

Other technological advancements, particularly those associated with Industry 4.0, such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain are also impacting production methods and transport-related emissions (Anthony et al., 2024). Industry 4.0 technologies serve as facilitators for transformation, allowing logistics providers significant opportunities to enhance the fundamental structures and capabilities of their SCM systems (ibid). IoT allows real time tracking and predictive analytics, which help balance just-in-time (JIT) production with more efficient shipment frequencies. This mitigates the risk that lean inventories might otherwise increase transport emissions through more frequent deliveries (Zhang et al., 2022). AI optimisation enables more efficient scheduling and routing, reducing fuel consumption and transport emissions according to Shawon et al. (2025). Moreover, according to Ojadi et al. (2025), blockchain technology boosts transparency and coordination, which can also help reduce unnecessary transport.

In a conclusion, changes of production methods, especially through the adoption of decentralised manufacturing and advanced digital technologies, are promising for the reduction of transport-related emissions, as these may allow shorter supply chains, simpler logistics and real time data to make more sustainable decisions.

2.4 Transport modes

The selection of transport mode has a direct impact on transport-related emissions. Benjaafar et al. (2013) pointed out that these decisions may have a significant impact on a buying firm's carbon footprint. Hence, by shifting to less emitting transport modes, buying firms can reduce their transport-related emissions.

The emission intensity of different transport modes varies considerably. Data from The International Transport Forum (2022) show that CO_2 emissions per ton-kilometre for road transport are typically about twice as high as for sea transport and almost 10 times higher than for rail freight. This underlines the importance of strategic modal choices in efforts to mitigate environmental impacts. The variation in emission intensity is reflected in the current distribution of transport emissions. Road freight, which dominates the sector, is responsible for 74 per cent of global transport emissions, due to its heavy reliance on fossil fuels (Girteka, 2024). In contrast, rail freight offers a noticeably lower carbon footprint and electrified rail systems, which are growing in Europe, help to further reduce emissions (ibid). Air freight continues to grow steadily, and the EU is actively addressing its emissions through measures that aim to incentivise emissions reduction (EC, 2024). Although sea freight is more efficient than road, it remains a significant and growing source of emissions, with global shipping projected to increase its emissions by up to 130 per cent of 2008 levels by 2050 if action is not taken (ibid).

Empirical studies further highlight the benefits of switching to less carbon-intensive modes. For instance, Winebrake et al. (2008) conducted three case studies to demonstrate freight emissions reductions resulting from shifting to less emitting transport modes. The results of these case studies suggest that as the amount of transport increases, it will be important to focus on rail and maritime transport. However, the practical implementation of modal shifts is often constrained by operational and infrastructural limitations. Kreutzberger et al. (2003) emphasised that the accessibility of these transport modes is not always possible. Hence, shifting to intermodal or multimodal transport – integrating multiple transport modes within a single supply chain – can be an approach to reduce carbon emissions. Similarly, Craig et al. (2013) analysed more than 400,000 shipments to check whether switching from truck to rail or using both was more efficient and environmentally friendly. They concluded that, overall, the use of intermodal transport can contribute to reduce CO_2 emissions, but benefits vary according to routes.

Modal shift, along with changing to more efficient vehicles and low carbon fuels, is often listed as one of three key approaches to lower emissions from transport (Björk et al., 2023). However, despite the recognised potential of modal shift to reduce transport-related emissions, there is a lack of evidence of modal shift realisation in most countries (ibid). Australia, Italy, and Slovenia are the only OECD countries that have successfully shifted freight from road transport. Björk et al. (2023) pointed out that, in Europe, modal shift objectives are basically guided by the Transport White Paper (European Commission, 2011), which determines that 30 per cent and 50 per cent of road transport over 300 km should be replaced by more energy-efficient modes by 2030 and 2050, respectively (ibid). They estimated that, in Sweden, for example, shifting freight from heavy trucks to shipping could reduce CO_2 emissions by 4–11 per cent. This illustrates the substantial environmental benefits that can be achieved through initiatives focused on modal shift (ibid).

To conclude, there is evidence that shifting from high-emission modes such as road and air freight to lower-emission alternatives like rail and sea transport can create substantial environmental benefits. While the selection and integration of transport modes has the potential to reduce transport-related emissions, realising this potential requires addressing a range of infrastructural, operational and policy-related challenges.

2.5 Vehicles and fuels

Vehicle and fuel type have a direct impact on transport-related emissions. According to Björk et al. (2023), two key approaches to lower emissions from transport are changing to more energy-efficient vehicles and low carbon fuels. Their research highlights that technical innovations such as increased battery efficiency, electrification and alternative fuel sources, and the automation of vehicles, can ensure substantial reductions in energy consumption per unit of freight moved. They also found that fuel type has an equally significant impact on emissions. Switching from fossil fuels to alternative fuels such as hydrogen, biodiesel and electricity can reduce transport-related emissions.

This was corroborated by Ferre & Thomé (2023), who conducted a comprehensive literature review to present an overview of the current state of carbon mitigation in the transport sector. They found that transport service providers can contribute to the reduction of transport-related CO_2 emissions by adopting the use of alternative fuels and electric vehicles. They noted that the effectiveness of the transition to electric vehicles is dependent on the carbon intensity of the electricity supply and availability of charging structure.

In addition to vehicle and fuel selection, operational practices play a key role in determining emissions in practice. McKinnon (2010) argued that logistics providers can work on reducing the carbon intensity of the energy they use and increase the energy efficiency of their operations by improving the technical features and the maintenance of their vehicles. Regular vehicle maintenance can improve fuel efficiency and reduce emissions.

Several authors have identified the importance of collaboration to reduce emissions by using of less emitting vehicles and fuels. Carter and Rogers (2008) suggested that companies can support and encourage suppliers to engage in environmental activities, to use more fuel-efficient vehicles and to share their emission data. This was also stressed by Koh et al. (2023), who suggested that firms can reduce the transport and logistics carbon footprint of their supply chain by working together with their suppliers and helping them to adopt more sustainable transport practices and use vehicles that emit less CO_2. The importance of collaboration with transport service providers has also been highlighted. For instance, Ferre and Thomé (2023) found that transport service providers can contribute to the reduction of transport-related CO_2 emissions by adopting the use of alternative fuels and electric vehicles.

It can be concluded that the relation between vehicle technology, fuel choice and operational efficiency fundamentally shapes the conditions for transport-related emissions. While the transition to energy-efficient vehicles and low-carbon fuels is a key to achieving relevant emission cuts, making these strategies a reality demands an integrated approach that also considers maintenance, operational practices and the local energy system.

2.6 Summary of previous research on the five areas and how they relate to each other

The geographical distribution and strategic selection of suppliers significantly influence transport-related CO_2 emissions. Empirical and theoretical studies show that sourcing from geographically closer suppliers can reduce transport distances, emissions and costs (Ellram et al., 2022). Despite this, many firms still overlook their responsibility for upstream freight emissions (Katiraee et al., 2024). The complexity of supplier networks needs collaborative management to optimise logistics and environmental performance.

Integrating sustainability into supplier selection and fostering buyer–supplier collaboration are key for reducing emissions and enhancing supply chain resilience.

Lead time requirements within supply chains have direct implications for transport emissions. Short lead times often need urgent shipping, particularly air freight, which is highly carbon-intensive (Arikan et al., 2014). Conversely, reducing lead time demands enable shipment consolidation and better vehicle utilisation, which contributes to lower emissions (ibid). Flexible lead times also support the adoption of slower, more sustainable transport modes (McKinnon, 2016). Industry and academic sources advocate for 'despeeding' supply chains to mitigate emissions, though this must be balanced with operational demands. Ultimately, managing lead time requirements is crucial for aligning logistics efficiency with environmental objectives.

Production methods, especially the shift toward decentralised and digitally enabled manufacturing, play a key role in shaping transport demand and emissions (IEA, 2023). For example, AM and Industry 4.0 technologies allow localised production, simplified supply networks and reduced material flows, all of which contribute to lower transport-related emissions (Forge, 2025). AM enables the design of products with fewer components, reducing the number of suppliers and transport stages (Ford and Despeisse, 2016). Technologies such as IoT, AI, and blockchain further enhance logistics efficiency through real time data, predictive analytics, and improved coordination (Anthony et al., 2024). These innovations collectively support the development of shorter, smarter and more sustainable supply chains.

The selection of transport modes is a key determinant of supply chain emissions, with air and road freight being the most carbon-intensive modes (Girteka, 2024). Rail and maritime transport offer significantly lower emission profiles, and electrified rail systems present further opportunities for decarbonisation (ibid). While modal shifts have been recognised as effective strategies for reducing emissions, their implementation is often constrained by infrastructure and operational limitations (Björk et al., 2023). Intermodal and multimodal transport solutions can help overcome these barriers, although their effectiveness varies by route and context. Policy initiatives, such as the EU's Transport White Paper, aim to promote modal shifts, but realisation remains limited, which highlights the need for more planning and investment that will make modal shifts possible (European Commission, 2011).

Vehicle technology and fuel type directly influence the carbon intensity of transport operations (Björk et al., 2023). Transitioning to energy-efficient vehicles and low-carbon fuels, such as electricity, hydrogen and biodiesels, can significantly reduce emissions (ibid). The success of these transitions depends on factors like energy grid composition, infrastructure availability, and operational practices (McKinnon, 2010). Regular vehicle maintenance and technical upgrades further enhance fuel efficiency (ibid). Collaboration between firms, supplier, and transport providers is essential to support the adoption of sustainable vehicles and fuels (Ferre &Thomé, 2023). Hence, a holistic approach that integrates technological innovation, operational efficiency, and supply chain coordination is necessary to achieve meaningful emissions reductions.

There are many ways to reduce transport-related emissions in upstream supply chains. Previous research has highlighted five key areas: supplier base and location, lead time requirements, production methods, transport modes, and vehicles and fuels. Each offers potential for environmental improvements. These five areas for reducing transport-related emissions form tightly interconnected links where decisions in one cascade into others. For example, supplier locations determine feasible transport modes, which will define vehicle and fuel use; lead times constrain both sourcing and transport choices; and production methods could reconfigure supply chains in ways that reshape all the above. The literature provides several examples of these interconnections. McKinnon (2010) pointed out that having suppliers located closer to the buying firm supports the use of less emitting transport modes. Arikan et al. (2014) highlighted that short lead time requirements can trigger the use of high emitting transport modes. McKinnon (2016) discussed that sourcing locally could enable the switch to the use of low carbon fuels. Gibson et al. (2021) noted that adopting AM can reduce the number of suppliers. Switching transport modes can also allow the use of less emitting vehicle and fuels (Girteka, 2024).

Recognising and managing these interconnections is essential for designing low carbon and resilient supply chains. Transport is closely interdependent with other activities and resources. Hence, every situation requires analysis to identify suitable ways of achieving reductions in transport-related emissions.

3. Frame of reference and problem discussion

This chapter starts out by addressing three central themes: (1) the INA, (2) transport activities as embedded in supply networks and (3) strategic purchasing issues. The chapter ends with a problem discussion.

To recap, the aim of this thesis is to explore how buying firms can reduce transport-related climate impacts from their upstream supply chains and to identify the main challenges and opportunities in doing so. An important point of departure for this thesis is that transport activities play a key role in the exchange of goods in supply networks since every exchange of goods between buying and selling firms typically creates a corresponding need for transport. Hence, a main challenge for buying firms when aiming to reduce the climate impact from transport is the integration of transport activities in supply chains (Eriksson et al., 2022). This integration means that firms often lack knowledge about the transport activities that are integrated in their supply chains, something that makes it hard to act.

A theoretical framework that can capture the integration of transport activities in supply chains is therefore required to achieve this aim. The INA (e.g. Håkansson, 1987; Håkansson and Snehota, 1995) enables a network perspective on supply chains, highlighting the interconnectedness among involved actors, resources, and activities beyond the boundaries of single supply chains. This means that transport activities, being one kind of activity in supply chains, can be captured in their network context. Hence, in this thesis ‘supply chains’ will be conceptualised as supply networks. Furthermore, the INA enables the conceptualisation of supply networks as interconnected business relationships that highlight the interdependencies and embeddedness of firms within supply networks. Thus, examining transport activities as embedded in supply networks acknowledges that decisions about transport are closely linked to the buying firm’s other decisions concerning the ‘supply side’ and that transport activities should not be treated as an isolated activity.

Hence, other relevant considerations related to a buying firm’s purchasing and supply strategies influence how the buying firms can reduce their transport-related climate impacts. A discussion on purchasing and supply strategies and how they impact the possibilities to reduce climate impact from transport is included in the frame of reference.

3.1 The Industrial network approach

This thesis is theoretically grounded in the INA (see, e.g., Håkansson, 1987; Håkansson and Snehota, 1995), which conceptualises the business landscape as a network of connected business relationships. Therefore, every firm is dependent on other firms through these business relationships, as well as the activities performed, and resources activated within these business relationships. Consequently, the INA provides a conceptual framework to analyse interconnected business relationships and interdependencies among activities and resources.

The INA conceptualises business networks in three analytical layers: actors, resources and activities (see Figure 2). Each layer can be analytically separated but is tightly connected to the other two (Håkansson, 1987). Actors are characterised by their capacity to initiate and execute actions. They exist at various levels, such as firms, departments within firms, and individuals. Actors perform and coordinate activities, and control resources. Furthermore, resources are activated by the activities. Resources may be classified as either physical (such as machinery, material, and vehicles) and non-physical (for example, labour and knowledge). Typical examples of activities include assembly, production, machining, transport, and materials handling (ibid.)

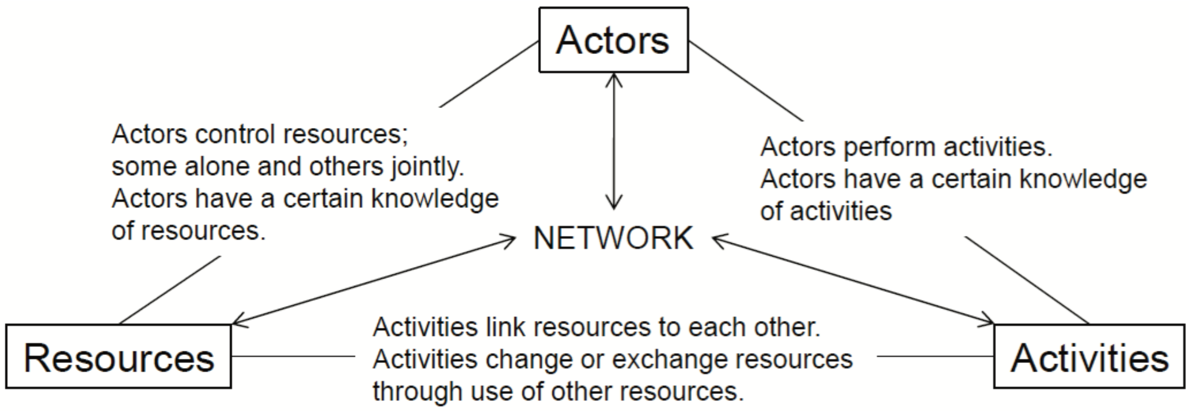

Figure 2. The network model (Håkansson, 1987: 17)

Håkansson and Snehota (1989), affirmed that business relationships develop between firms as a result of their interactions and exchange processes. Furthermore, through its business relationships firms can access the resources of others. Firms also need to coordinate their activities with other firms' activities. Thus, the performance of a firm depends largely on whom it interacts with.

3.2 Transport activities as embedded in supply networks

Browne et al. (2023) conceptualised the transport system as consisting of three layers and two interfaces (see Figure 3). The layers are the supply chain layer, the transportation layer and the infrastructure layer. The market for transport services is the interface between the supply chain and transportation layers since the exchange of goods in the supply chain layer generates a need for transport services, which, in turn, is exchanged into the market for transport services. Furthermore, traffic is the interface between the transportation and infrastructure layers as a result of transport activating the infrastructure and, in turn, generating traffic.

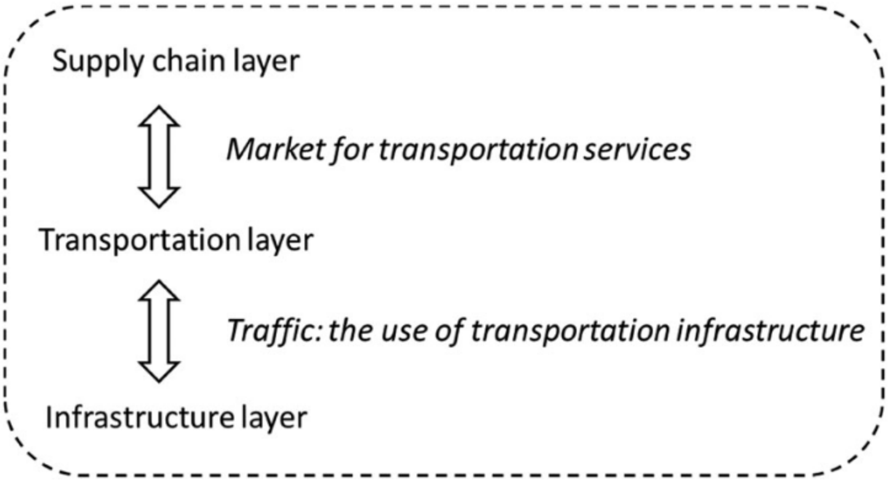

Figure 3. The transport system (Browne et al., 2023).

According to Browne et al. (2023) the supply chain layer is characterised by tight couplings due to the various adaptations taking place in the exchange of goods. This is due to various adaptations made in this layer, such as JIT arrangements and make-to-order production. Hence, interdependencies between buyers and suppliers in the supply chain level are high, both within and across supply chains. When the transport layer is concerned, this is instead characterised by loose couplings. This is because the resources in this layer, such as trucks, trains and ships, are mainly standardised, which enables these resources to be used for many purposes. Furthermore, this layer is characterised by a few large firms co-existing with many small firms, together forming a complex transport and logistics network of rather independent actors. The market for transportation services (the interface between the supply chain layer and the transportation layer) is also characterised by loose couplings. For many firms, decisions concerning transport purchasing are not of strategic concern but come as a result of other decisions that are considered more strategic. For example, decisions to outsource and offshore production activities to low-cost countries in order to reduce cost for production may lead to increased demand for transport (ibid).

According to Coyle et al. (2003), transport can be regarded as the physical link between production and consumption units in a supply chain. Furthermore, Eriksson et al. (2022) illustrated how transport activities are embedded in supply networks, both 'vertically' in supply chains and 'horizontally' across different supply chains. This means that if a firm wants to reduce the climate impact from transport activities, it must consider transport activities as connected to other transport activities as well as to other types of activities, such as production activities. Hence, a buying firm's efforts to reduce transport emissions upstream should be analysed in its network context where transport activities are viewed as a result from the exchange (of the products subject to transport) between firms in business relationships but also as integrated in the business network where other decisions – such as those relating to (out)sourcing and production – shape transport demand and the climate impacts resulting of it.

The TST offers a key unit of analysis to analyse how transport is embedded in supply networks (Eriksson et al., 2019). This analysis captures the interface between the supply chain layer and the transport layer, as discussed by Browne et al. (2023). The TST relies on each exchange of goods between a buyer and seller (in the supply chain layer) generating a need for transport (in the transport layer). The TST consists of the relationship between the buyer and seller of goods (in the supply chain layer) and the relationship between the buyer and seller of transport services (in the interface – market for transport services). In this relationship, either the buyer or seller of goods is the buyer of transport services. According to Andersson et al. (2018, p. 254), 'The TST includes an indirect link between the transport service provider and buyer (of goods), or alternatively between the transport service provider and supplier (of goods). Hence, the TST provides a unit of analysis for understanding this important indirect link and the embeddedness of transport services in supply networks'. This is shown in Figure 4, on the top the situation when the supplier is the buyer of transport services is provided, and on the bottom the situation when the buyer of goods is the buyer of transport services is provided.

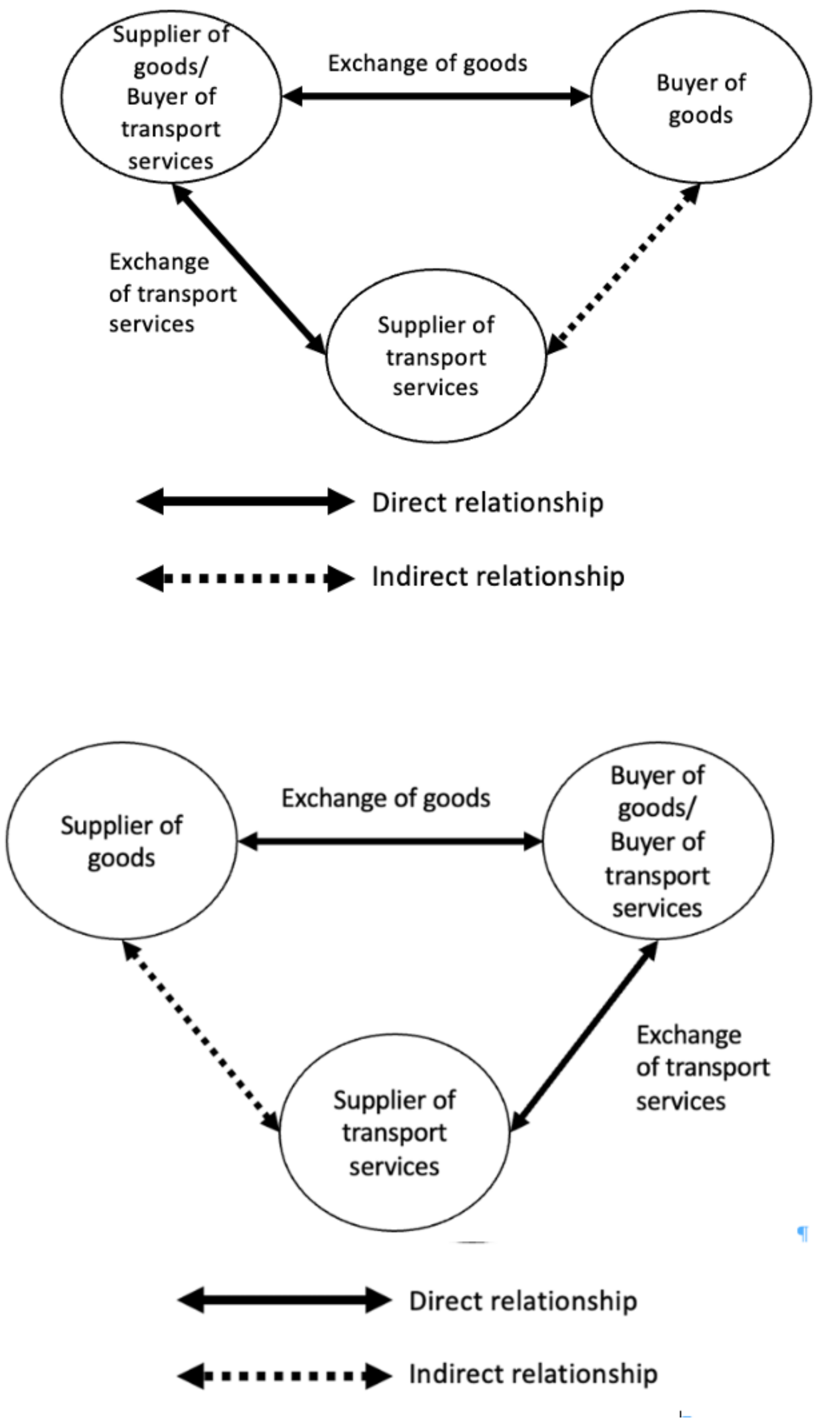

Figure 4. The Transport Service Triad (Eriksson, 2019)

3.2.1 Transport activities and interdependencies

Regarding activity interdependencies, vertical interdependencies (sequential, within supply chains) need coordination within and across firm boundaries (Richardson, 1972). Owing to this vertical, or sequential interdependence, plans are needed to coordinate the activities undertaken by different firms (ibid.). According to Richardson (1972: 889), complementary activities represent ‘different phases of a process of production and require in some way to be co-ordinated’. Furthermore, activities are closely complementary when there is a need to ‘match not the aggregate output of a general-purpose input with the aggregate output for which it is needed but of particular activities’ (ibid.: 891) and when ‘relational governance’ is required; that is, adjustments are made in relation to specific counterparts such as suppliers.

However, activities are also subject to horizontal interdependence based on their use of joint resources; that is, across supply chains (Dubois et al., 2004). Richardson (1972: 888) said that these kinds of activity are similar when they ‘require the same capability for their undertaking’. The notion of horizontal interdependence can also be related to new forms of horizontal collaboration among firms aiming to better utilise transport resources that have become recognised as one of the means to address transport-related emissions. Hence, firms can develop horizontal collaborations to make use of the compatibility between their transport demands (Holmberg et al., 2014; Basso et al., 2019). Such efforts among otherwise unrelated firms can result in improved performance as well as economic and environmental benefits (Eriksson et al., 2022).

These generic activity interdependencies are vital when analysing how transport activities are embedded in supply networks and for analysing change in these supply networks. This is in line with Eriksson et al. (2022), who argued that it is key to consider both sequential and horizontal interdependence when analysing transport activities as embedded in supply networks. For example, sequential interdependence implies that transport activities are sequentially interdependent with other transport activities as well as other types of activities, such as production activities. This implies that one activity’s output becomes the input for the next. Horizontal interdependence implies that transport activities share common resources across supply chains. Hence, when approaching the phenomenon in this thesis, these types of interdependencies become a main concern for firms to consider.

3.3 Strategic purchasing issues

The way firms approach purchasing has been a concern in industrial and business strategy, with purchasing strategies evolving from transactional, price-focused approaches towards more strategic and network-oriented practices (Gadde & Håkansson, 1994; Gadde et al., 2010). According to those authors, purchasing is not only an operational function but a strategic activity that can influence a firm’s competitiveness and capacity for innovation (ibid). According to Gadde et al. (2010), purchasing strategies are vital for effectively managing relationships with suppliers, ensuring the quality and timely delivery of materials, and cost savings in the supply chain. The authors also highlighted the shift from traditional purchasing approaches towards more collaborative and relationship-based strategies. This shift was reinforced by Knight et al. (2022), who discussed opportunities for 'business-not-as-usual' PSM research. This approach highlights the importance of collaborative and relationship-based strategies in the context of PSM. The authors emphasised the need for PSM professionals to work with a diverse range of stakeholders, including economists, innovation policy leads, public agencies, and non-governmental organisations (NGOs). They also showed the significance of intra-organisational collaboration with functions like research and development (R&D) and production to enable circular products, processes, and supply chains. These collaborative approaches are seen as essential for developing new business ecosystems and addressing challenges in the evolving business landscape.

Gadde and Håkansson (1994) suggested that a buying firm should consider three purchasing issues: (1) the decision to make or buy (whether to rely on in-house production of goods or services or to buy from suppliers), (2) the supply base structure (regarding the number of suppliers to use, as well as how the suppliers should relate to one another), and (3) the nature of the supplier relationships (firms must consider whether to foster close cooperation with a few strategic suppliers or maintain flexibility through looser ties with multiple vendors).

The decision concerning make-or-buy involves choices about resource allocation, cost structure, and long-term sustainability for a company. In many firms, purchasing accounts for more than half of the total costs (Gadde & Håkansson, 1994; Gadde et al., 2010; Schiele, 2019), which makes the make-or-buy decision a critical strategic choice. As firms rely more on outside suppliers for resources, the make-or-buy decision becomes very relevant in determining the company's capabilities. Hence, strategic allocation of resources through make-or-buy decisions is key for long-term success.

The supply-base structure directly impacts a company's ability to influence its supplier relationships (Gadde & Håkansson, 1994). Firms are reducing the number of suppliers to create partnerships with key suppliers as part of their purchasing strategy (ibid). Coordination among suppliers is a key aspect of supply-base structure, which, as a strategic purchasing issue enables deeper collaboration, improved communication, and enhanced overall supply chain performance (ibid). Reducing the supply base aims to improve coordination, enhance relationships, and achieve greater efficiency in the supply chains, by shifting the focus from transactional purchasing to strategic collaboration (ibid). This is because a smaller and more structured supplier network enables firms to move beyond price-driven competition toward deeper, long-term partnerships that foster mutual adaptation and joint problem-solving (ibid). More recent articles have highlighted that buying firms are consolidating their supply base to ensure more collaborative, focused and strategic relationships (Wieland & Ivens, 2025). Jones (2024) pointed out that many firms intentionally reduce supplier numbers to deepen collaboration with those considered strategic, despite increased dependence, aiming for innovation, risk-sharing, and long-term mutual growth.

The nature of supplier relationships determines which benefits can be gained from working with these suppliers. Gadde and Håkansson (1994) argued that when relationships shift towards closer relationships, this can lead to mutual benefits. Hence, close cooperation with individual suppliers is key to achieving benefits related to technical development, which can drive improvements in quality, innovation and cost efficiency, leading to strategic advantages in the marketplace.

Hence, there are some key issues to consider for buying firms. However, in the discussion above these issues were discussed on a 'general level', not focusing specifically on goods, transport, or some other service. The focus of the present thesis is on how a firm can reduce its transport-related climate impacts in its upstream supply network. With the TST in mind, and the implication of transport being embedded in supply networks, this means that firms need to consider this 'problem' both from the perspective of transport service purchasing but also from the perspective of many other concerns relating to sourcing and purchasing from the firm's perspective.

3.4 Problem discussion

This thesis focuses on how buying firms can reduce transport-related CO_2 emissions generated by their purchasing activities. These emissions are most often categorised as Scope 3 emissions since they are carried out by transport service providers and are therefore external to the buying firm. However, these emissions are heavily affected by a range of purchasing decisions such as (product and transport service) supplier selection, lead time requirements, as well as choices of production methods, transport modes, vehicles and fuels. Hence, these emissions result from various decisions on the buying side of firms that impact on the structure and dynamics of their supply networks in which transport activities are embedded.

The relevance of purchasing strategies in reducing CO_2 emissions is a crucial aspect of sustainable SCM. By adopting sustainable procurement practices, firms can contribute to lower carbon emissions throughout the supply chain. This is supported by Sarkis et al. (2010) and Novitasari & Agustia (2021). They highlighted the positive impact of purchasing strategies on reducing CO_2 emissions, contributing to achieving long-term environmental sustainability goals.

By prioritising suppliers that focus on sustainability, promoting the use of renewable resources, and fostering collaboration with key stakeholders, firms can significantly lower their CO_2 emissions (Onukwulu et al., 2021). Studies have shown that strategic sourcing decisions, such as selecting suppliers based on their environmental performance and investing in green technologies, can lead to a substantial reduction in CO_2 emissions (Ma et al., 2022). Furthermore, embracing circular economy principles and focusing on resource efficiency in purchasing practices can help minimise waste and energy consumption, further contributing to emission reduction goals (Sarkis et al., 2020). By incorporating sustainability criteria into their purchasing strategies, firms can not only mitigate environmental risks but also drive innovation, enhance reputation and achieve cost savings in the long run.

The embeddedness of transport activities in supply networks creates both challenges and opportunities for buying firms. From a network perspective, transport is not an isolated activity, but a consequence of interdependent activities and of connected relationships between actors. The INA provides a useful analytical tool to understand these interdependencies, highlighting how actors (for example, firms and departments), resources (such as vehicles and infrastructure), and activities (transport, purchasing, production, etc.) are interconnected. The TST further highlights the triadic relationship between the buyer of goods, the seller of goods and the transport service provider, indicating how decisions made by these actors impact how transport activities are carried out.

Numerous changes must be made to transform the transport system into a more climate-neutral system, which requires a broad range of actions (Dolge et al., 2023). While technological advancements such as alternative fuels and energy-efficient vehicles are essential to reduce transport-related CO_2 emissions, reducing the climate impact of the upstream transport activities embedded in the supply network of a company requires more than technological changes. Hence, transport needs to be analysed as part of the wider logistics and supply network context (Eriksson et al., 2022). Since transport activities are interdependent with other activities, both within and across firm boundaries, companies need to work on internal adjustments as well as interacting in relationships with other actors. It is also vital to address supply chain reconfigurations. As stated by McKinnon (2021, pp. 104–123), although ‘the switch to low carbon energy, particularly for road and rail modes, will ultimately deliver much of the required decarbonization, this will need to be supplemented by a reconfiguration of supply chains'.

In this context, the present study investigates what an individual company can do to reduce the transport-related CO_2 emissions in the company's upstream supply chains. This includes the analysis of how companies' purchasing behaviour contributes to transport-related climate impact, both directly – through procurement of transport services – and indirectly, as a result of how they select, and work with, their products' suppliers. In addition to firm-internal conditions, there are various external factors to consider, such as the geographical location of suppliers, the transport modes available, the transport infrastructure, as well as the services offered by transport service providers and the requirements of their other customers. Efforts to reduce the climate impact of transport upstream are also greatly affected by the fact that transport is often included in product purchases and is therefore not visible to or known by buying companies. This entails a limited 'horizon' for buying companies in understanding how their product purchases affect transport emissions and what they can do to reduce these emissions (Eriksson et al., 2021). The case illustrates the problem of not considering parts of the network when initiating a change. This points to the problem of having a myopic network horizon, which makes it hard to identify the relevant part of the horizon of a certain change initiative. Moreover, these situations stress the importance of interacting with all parties involved in the TSTs.

Swanson et al. (2018, p. 113) argued that many scholars consider 'relationships with customers, suppliers and logistics service providers as the most important focus of Supply Chain Management'. Furthermore, SCM scholars seem to agree that there is a need to expand the scope from dyadic business relationships to triads and/or networks (see, e.g., Carter et al., 2015). Eriksson et al. (2022, p. 89) stated that 'the combination of vertical and horizontal interdependence entails that (dyadic) business relationships between customers and suppliers of transport services/activities develop networks of connected business relationships'. A network model (such as the INA) supports analysis of relationships with other parties representing the context within which the organisation interacts (Håkansson & Snehota, 1989). The notion of supply networks has become key in SCM, together with a growing awareness of that sustainability efforts require new thinking about how best to influence and manage supply networks (Johnsen, 2018). Hence, a network approach is useful for analysing the activity interdependencies, the use of resources and the business relationships in different supply chain configurations, and also to address the effects of supply chain reconfigurations aiming at reducing transport-related emissions.

Apparently, transport resources and their use are central in efforts to reduce emissions. Based on how transport activities are embedded in supply networks, the relevant scope of collaboration with different parties on different efforts can be addressed. Such collaborations permit joint exploration of the conditions for use of less or better transport resources, resulting in improved performance through more efficient use of existing resources, use of more sustainable transport resources and/or by allowing transport providers to better combine transport modes in their networks (Eriksson et al., 2022).

To summarise, the challenges facing buying firms aiming to reduce CO_2 emissions arise because transport is deeply embedded within supply networks, wherein actors, resources, and activities are closely interconnected. The present study aims to explore these challenges to support buying firms in their efforts to reduce their climate impact from transport.

4. Methodological considerations

This chapter presents the methodological considerations applied in the study underlying the thesis. It starts by introducing the research setting and the researcher's background, followed by the research design. Then the data collection is presented. The chapter ends with a description and some reflections on the research process.

4.1 Research setting

The study, which is part of a doctoral project, is a collaboration between Chalmers University of Technology and the case company Focal Manufacturing Company (henceforth referred to as FMC). The research is funded by Triple F (Fossil Free Freight), which is a programme funded by the Swedish Transport Administration's research and innovation initiative. Triple F focuses on three challenges: a more transport-efficient society, a switch to energy-efficient, fossil-free vehicles and a shift to renewable fuels. In addition, it works across three themes: logistics, technology and policy. This project primarily focuses on the challenges related to a more transport-efficient society and the theme logistics.

Before starting the position as a PhD student, I spent approximately 15 years working in management consulting all over the Americas and Europe. For the last four of those years I worked as a project manager, leading global projects in different industries. My focus was on driving process improvements, developing strategies, and implementing best practices. I also have experience in industry and in the NGO sector, mainly in finance and sustainability. My professional experience allowed me to develop hard skills (such as process mapping and project planning) and soft skills (such as communication and adaptability) that have been useful when working as a PhD student. I am also a certified consultant of the ERP system used by the focal case company, which allows me to fully understand how transport is managed in the system – from the moment a contract is created, the materials/components are ordered, received and paid for. Academically, I hold a Master of Arts (MA) International Relations from Hult International Business School in England, which adds an indirect value to my PhD process, helping me to navigate complex stakeholder landscapes. Furthermore, I hold a Master of Science (MSc) in Environmental and Energy Management from the University of Twente in The Netherlands, which has given me a foundation in sustainability, a core theme in reducing transport-related emissions. I also have a double Erasmus Mundus Master of Science (MSc) in Circular Economy from the University of Graz in Austria and the Norwegian University of Science and Technology (NTNU) in Norway. This double degree contributed to my education in sustainable supply chain design, low-carbon systems and to develop an innovation mindset, all of which have direct relevance in my PhD topic. When I came across this PhD project – a study in collaboration between the university and a manufacturing company with a focus on sustainability that required a dialogue with multiple stakeholders – I felt it was a natural fit for me. The project's context aligns closely both with my professional and academic background, allowing me to contribute meaningfully to it, while I continue to develop as a researcher.

4.2 Research design

This study relies on a case study approach. A case study is a suitable research method when the phenomenon under study is context-dependent, complex and the underlying relationships are connected to a great extent (Flick, 2009), as is the case in the present study. This is reinforced by Yin (2013), who affirmed that a case study approach is suitable if a deep understanding about a phenomenon is needed, which is also the case with the present study. The phenomenon under investigation – how buying firms can reduce transport-related climate impacts in their upstream supply chain – is context-dependent. It is shaped by multiple factors, such as suppliers location, organisational priorities and infrastructure availability, which influence the feasibility of ways of reducing climate impacts and their effectiveness. The phenomenon is also complex because it involves environmental, economic and logistical considerations, impacted by decisions made by multiple actors across several tiers of the supply chain. Regarding connected relationships, buying firms must engage collaboratively internally, within different departments, and externally, with multiple suppliers and transport providers, to implement successful changes. For these reasons, the methodology applied in this research is an in-depth case study that was conducted in collaboration with a focal firm.

According to Dubois and Gadde (2002), the key difficulty of case studies is addressing the interrelatedness of the various elements in the research work. This is particularly relevant for this study, as its phenomenon is characterised by a high degree of interdependence among multiple actors, processes and contextual factors. For instance, purchasing – and even some production – decisions made by the buying firm are closely linked to other elements. Dubois and Araujo (2007) highlighted that case studies are recognised as a valuable methodological approach, as they enable iterative and context-dependent exploration of a phenomenon with the objective of capturing important features of a specific case through the application of a particular framework. In this regard, the systematic combining process, as outlined by Dubois and Gadde (2002), offers a suitable approach for this study, as it involves continuous and dynamic interaction between theory, empirical data and case analysis, allowing the researcher to refine both the framework and the understanding of the phenomenon as the study progresses.

In this study, a systematic combining process was applied, helping to address the interrelatedness of various elements within the research context, as the study has several dimensions – logistical, environmental and organisational - tightly intertwined. The use of a systematic combining process also allowed a continuous refinement of both the frame of reference and the research questions, as new insights emerged from the data collected from interviews. For example, knowing about FMC work with AM, even if not with a focus on climate impacts, triggered an interest of researching how AM could impact on supply network reconfiguration and transport-related emission. Furthermore, FMC's ongoing development of new initiatives over the years further contributed to this dynamic. As the company introduced new initiatives to reduce their emissions, the research design was adjusted accordingly. This ensured that the study remained relevant and reflective of real-time transformations within the organisation.

For Chapter 2, a review of literature was conducted to explore relevant conceptual topics that were relevant for the study. The research process was carried out using Scopus, Chalmers Library and Google scholar databases. Rather than following a systematic review model, the process was iterative. For each topic, several different combinations of keywords were used to capture a broad range of perspectives and identify relevant contributions.

4.3 Data collection

The data collection was based on semi-structured interviews, both in person and online, participation in meetings and a workshop, and secondary sources of data, such as FMC's reports. The data collection started in September 2022 and is ongoing. So far, eight visits to FMC's location have been made. These visits are detailed in the next section, in the description of the research process.

Meetings and interviews were held digitally through Microsoft Teams or Zoom and in person during visits to FMC. Digital meetings ensured data collection continuity and facilitated flexible scheduling, also allowing for the participation of a broader range of FMC employees. However, interviews conducted in person during site visits to FMC provided more depth of understanding and interaction than digital meetings. The physical presence on site enabled richer communication, also allowing observations of how they work in their systems and how some production processes are executed.

Additionally, these face-to-face encounters contributed to the development of a more personal rapport and enhanced trust in the work with FMC employees.

4.4 Research process

4.4.1 Description of the research process

The research started with a first visit to FMC's site in September 2022. The visit was structured to introduce the project to FMC and to provide an overview of the company's organisation, core purchasing and shipping processes and sustainability initiatives. During this visit, several meetings were held involving me, my PhD supervisor, my examiner and representatives of FMC's sustainability, purchasing and shipment departments. The visit also included a tour around FMC's production facilities, where I was able to learn about their production process and see the products' components. On this occasion we were also able to learn about other sustainability projects.

The initial site visit provided information that allowed the initial project scope to be refined and the data collection to be directed. For instance, it was during this first visit that FMC's AM initiatives were mentioned, triggering an interest in the potential implications of the use of AM on transport-related emissions. Along with further interviews and literature search, this resulted in a journal paper (Alcantara et al., forthcoming). As part of the data collection, I had the opportunity to tour FMC's AM workshop to learn about the history of implementing this production method, both in general terms and with detailed insights into two specific components. For these components I also acquired knowledge and data about the differences between using CM and AM, which enabled a comparative analysis of the supply networks associated with these production methods for the two components. Furthermore, the data collection process enabled analysis of FMC's supplier networks for both components and both manufacturing approaches.

Over the course of the research leading to the licentiate thesis, I visited FMC eight times. These visits involved meetings and interviews with different departments. The visits also included presenting my PhD proposal for the Health, Safety and Environment (henceforth referred to as HSE) department, which hosts me at FMC. I also became engaged in discussions of a master's thesis carried out at FMC in a topic aligned to my research. At the end of 2024, I held a workshop aimed at sharing the preliminary findings of my study to FMC employees who had directly or indirectly contributed to my research with of information and data.

During my last visit in 2024 I was invited to take part in one of FMC's internal projects, an initiative to reduce transport-related emissions, since then I have followed the project through regular online meetings and by attending a workshop at FMC's site location.

I also had the opportunity to join a Net Zero Board[4] meeting, where FMC's sustainability initiatives were discussed.

The list of interviews, meetings and workshops is presented below in Table 2.

#	Date	Location	Duration	Interviewees role	Topic
1	20/09/2022	On site	1:30 hour	2 HSE managers Head of Sustainability	Introductory meeting about FMC and the company sustainability initiatives
2	20/09/2022	On site	1:30 hour	HSE manager Office manager	Purchasing department – structure and how it works
3	21/09/2022	On site	2 hours	HSE manager Head of Sustainability	Visit at the production workshop to see components and the manufacturing process
4	21/09/2022	On site	2 hours	HSE manager Shipment manager Logistic specialist	Shipping department – structure and how it works
5	07/11/2022	Online	1 hour	Data citizen specialist	Carbon emissions calculator "project" presentation
6	07/11/2022	Online	1 hour	Corporate logistics manager	Logistics department – structure and how it works
7	24/01/2023	On site	2 hours	AM manager	AM department – structure and how it works
8	25/01/2023	Online	1:30 hours	Corporate logistics digitalization specialist	Corporate Logistics department – how their TMS works
9	26/01/2023	On site	1:30 hours	Data citizen specialist	Carbon emissions calculator "project" practice demo
10	26/01/2023	On site	1:30 hours	AM manager	AM department - process mapping
11	10/05/2023	On site/ Online	1 hour	HSE team	Presentation of research proposal to the HSE department
12	11/05/2023	On site	1:30 hours	Procurement manager	Discussing research proposal and FMC suppliers relationship
13	04/10/2023	On site	1:30 hours	Head of AM	AM department - process mapping
14	05/10/2023	On site	1:30 hours	Production Engineer	CM department - process mapping
15	06/10/2023	On site	1:30 hours	Senior procurement engineer	Engineering department - AM and CM process mapping

[4] A net zero board refers to a corporate board of directors that explicitly integrates the achievement of net zero GHG emissions into its governance responsibilities, strategic oversight, and decision-making processes. They aim to ensure that corporate strategies align with internationally recognized climate goals, embedding science-bases targets into risk-management, investment and operational planning.

16	08/11/2023	Online	1 hour	Head of AM	AM department - process mapping
17	09/11/2023	Online	1:30 hours	3PL A manager HSE manager Shipping manager	3PL A green freight solution presentation
18	06/12/2023	Online	1 hour	Head of AM	AM department - process and supplier mapping
19	30/01/2024	On site	1 hour	Shipment manager Logistic specialist	Update about FMC transport emissions reductions initiatives
20	31/01/2024	On site	1 hour	Production engineer	CM process and supplier mapping
21	01/02/2024	On site	1 hour	Buyer	CM supplier mapping
22	27/02/2024	Online	1 hour	3 Senior buyers	AM process and supplier mapping
23	20/06/2024	On site	1 hour	Production Engineer	CM - processes and supplier mapping
24	20/06/2024	On site	1 hour	Head of AM Purchasing manager	AM process and supplier mapping
25	05/08/2024	Online	1 hour	Production Engineer	CM supplier mapping
26	14/08/2024	Online	1 hour	Production Engineer	CM supplier mapping
27	12/11/2024	On site	1 hour	Head of Procurement	Research preliminary results discussion
28	14/11/2024	On site/ Online	2 hours	HSE Manager Head of sustainability Head of AM Shipment manager Production Engineer 2 Business Excellence Project Managers Production Engineer 2 Senior buyers Graduate trainee for procurement	Workshop - presenting research preliminary results
29	15/11/2024	On site	1 hour	Graduate trainee for procurement	Master's thesis discussion
30	19/11/2024	Online	1 hour	Head of Am Production Engineer	Fine tuning traditional production mapping
31	19/11/2024	Online	1 hour	Senior procurement engineer	Engineering department - presenting research preliminary results
32	05/12/2024	Online	1 hour	2 Business Excellence Project Managers	First meeting supplier lead time reduction project
33	10/12/2024	Online	1:30 hours	Net Zero Board team	Net Zero Board meeting
34	27/01/2025	Online	1 hour	Graduate trainee for procurement	Supplier emission evaluation project
35	08/04/2025	On site	1 hour	Head of sustainability	Net Zero Board – history and how it works
36	09/04/2025	On site	2 hours	2 Business Excellence Project Managers 2 Buyers Shipment manager	FMC Lead time project workshop

37	10/04/2025	On site	1 hour	Shipment manager	Shipping department – transport emissions initiatives update
38	19/05/2025	Online	1 hour	2 Business Excellence Project Managers	Business Excellence – lead time project update
39	06/08/2025	Online	1 hour	2 Business Excellence Project Managers	Business Excellence – lead time project update and interaction with other departments to reduce transport emissions
40	11/08/2025	Online	1 hour	Shipment manager	Shipping department – interaction with other departments to reduce transport emissions
41	12/08/2025	Online	1 hour	Procurement manager	Procurement department – supplier emission initiative and interaction with other departments to reduce transport emissions
42	16/09/2025	Online	1 hour	2 Business Excellence Project Managers	Business Excellence – lead time project update

Table 2. List of interviews, meetings and workshops with FMC

Figure 5, shows the timeline from start of my PhD in August 2022 to licentiate degree in 2025, with some key milestones marked on it.

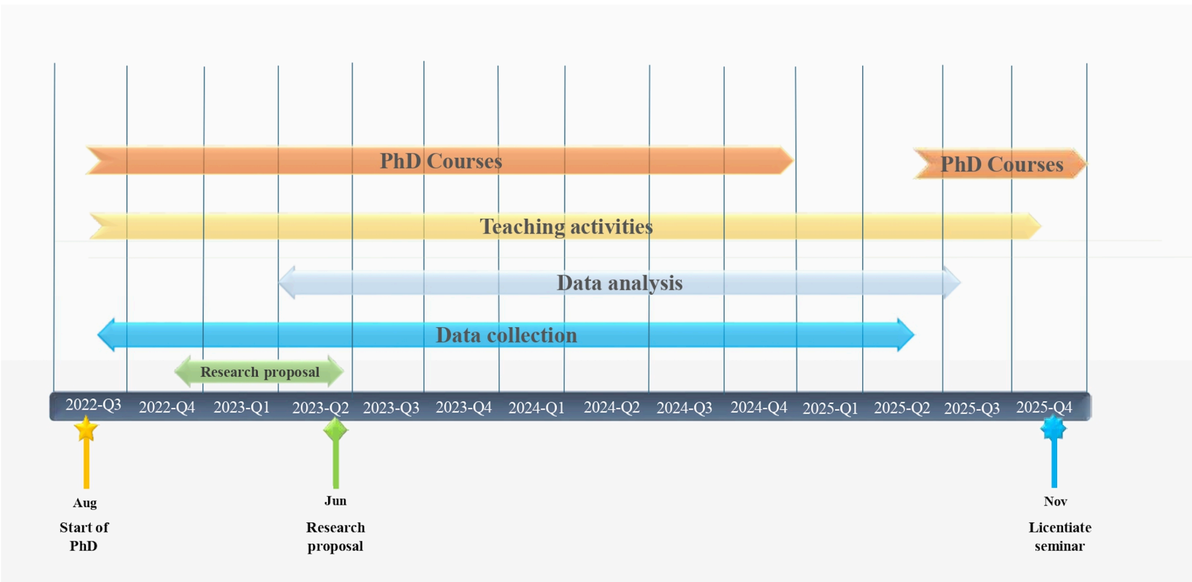

Figure 5. Timeline from start to licentiate degree

4.4.2 Reflections on the research process

Two key challenges were experienced early in the research process: limited visibility across departments and difficulties in accessing relevant data. Since reducing transport emissions is a new sustainability topic to be addressed by the company, and since other sustainability aspects are in focus in parallel, the firm-internal networks required to work on these matters are still not completely in place. In other words, there is still fragmentation in terms of data and involvement of functions and specialists that need to be involved. These challenges inspired literature search on internal and external organising in relation to efforts to reduce transport emissions. A conference paper has been written and discussed as a first step to develop the study of this issue (Alcantara et al., 2025).

This study benefited from the engagement of FMC's team in Sweden, which demonstrated interest in the project and has been willing to make themselves available and to share information. The collaboration has been extended by inviting me to join a new internal project related to reducing CO_2 emissions. Nevertheless, obtaining data has sometimes proven to be challenging because it is not always straightforward to identify the right person to get the data from, and also because sometimes information from other countries has been harder to access. These difficulties could be due to different cultural corporate behaviours or the fact that some employees from other countries are hesitant to share sensitive information, even when subject to a non-disclosure agreement (NDA).

On a positive note, the study has fostered more collaboration and interaction within FMC. The regular meetings, which on some occasions have brought together people who do not usually work together, have been beneficial to the study and to FMC's continued sustainability efforts in general.

5. The case

Chapter 5 is divided into three sections. First, Section 5.1 introduces the case company, FMC, giving an overview of its inbound and outbound activities and emissions, as well as how it works with suppliers and internally in relation to activities that, directly or indirectly, impact on transport. The latter includes a description of who is responsible for buying transport services and how they are working towards improving the sustainability of the transport services they buy. Second, Section 5.2 describes two initiatives in which FMC is working with suppliers to reduce their Scope 3 emissions. The final section, Section 5.3, explains how the implementation of AM has affected FMC's supply network reconfigurations for two components and the effects on transport emissions.

The case takes its starting point in how FMC can reduce the transport-related climate impact within its upstream supply chain in relation to one of its locations in Sweden. However, since transport service procurement also includes downstream transport services, the description touches on these as well.

5.1 Introduction to FMC

Focal Manufacturing Company (FMC) operates in the global energy sector with a focus on energy technology and transition, providing products, solutions and services. The case study focuses on FMC's Swedish facilities and its ambitions to reduce its upstream climate impact in relation to transport.

FMC's product assortment consists of several variants of the same type of product. The products differ somewhat in size, but in general they can be said to be very large and expensive, typically spanning several meters in each dimension and weighing hundreds of tons. Their price can reach into the high tens of USD millions. Approximately 50–60 products are produced annually in the Swedish facilities. The business processes at FMC focus primarily on lead time to customers and costs. The current average lead time to customers is around 9–10 months. Lead time remains a critical focus for logistics as, together with costs, this is key for customers' decision making. Customers generally make their buying decisions based on delivery time and price. FMC is contemplating adding climate impacts to costs and lead time considerations, as some customers are starting to ask for that information.

5.1.1 FMC’s supply network

FMC’s network of suppliers (of components and materials) consists of 1600 suppliers in 60 countries. In 2024, FMC made approximately 140,000 purchases from these suppliers, generating around 11,000 inbound deliveries to their facilities in Sweden. These shipments were primarily transported by road (66 per cent), followed by air (33 per cent), and sea (1 per cent). Regarding outbound deliveries, around 17,000 deliveries were made to around 650 different customers in 83 countries. Of these, 32 per cent were transported by road, 31.5 per cent by air, and 0.5 per cent by sea. An additional 36 per cent of the outbound deliveries used combined road and sea transport; however, the precise modal distribution within this category cannot be determined since these outbound shipments are classified as ‘projects’ and consist of a mix of products and components. On average, each new product requires the preparation of approximately 100 packages with parts of the product, some of which are consolidated prior to dispatch. For customers located in Europe, the transport mode used is road. For customers located outside Europe, the transport modes used are road and sea. Table 3 provides a summary of inbound and outbound transport percentages by transport mode.

Transport mode used (2024)	**Inbound transport**	**Outbound transport**
Road	66%	32%
Air	33%	31.5%
Sea	1%	0.5%
Projects (road and sea)	-	36%
Total share	100%	100%

Table 3. Summary of FMC's inbound and outbound transport by transport mode in 2024.

FMC has a global strategy for supplier selection that the Swedish part of FMC must comply with. This strategy is focused on prices which results in a supplier base made up of suppliers that are geographically distant but offer low prices. In addition to this global strategy FMC sometimes uses other selection criteria when selecting suppliers. For example, when selecting a supplier, the buyer wants to make sure the key performance indicator (KPI) of on-time delivery (OTD) will be fulfilled. This is because late deliveries can disrupt production schedules, leading to missed deadlines, increased costs and potentially dissatisfied customers. Other criteria that can be considered by the responsible buyer are decided on a case-by-case basis. For example, when choosing heat treatment suppliers, the buyer supporting the AM department takes FMC’s needs and the supplier’s production capacity into consideration. The buyer considers how many units need the heat treatment and how much time it will take for the units to be ready. The buyer also considers whether the units can be sent together in one batch. Buyers of components work with preferred suppliers according to the commodity strategy for the commodities they are responsible for. Some commodities have several preferred suppliers; others have a single supplier.

Inbound transport to the Swedish facilities is organised differently depending on what Incoterms are specified in the contracts with the suppliers. Incoterms are a set of rules that specifies business-to-business contracts, defining the responsibilities of buyers and sellers of goods in relation to transport. In FMC's case, 80 per cent of the suppliers are responsible for buying the transport services for their goods, hence applying the Incoterm DAP (delivery at place) in their contracts. The remaining 20 per cent of the suppliers work according to the Incoterm FCA (free carrier) where FMC is responsible for buying the transport services. Figure 6 describes the different responsibilities that the Incoterms imply for sellers and buyers, respectively.

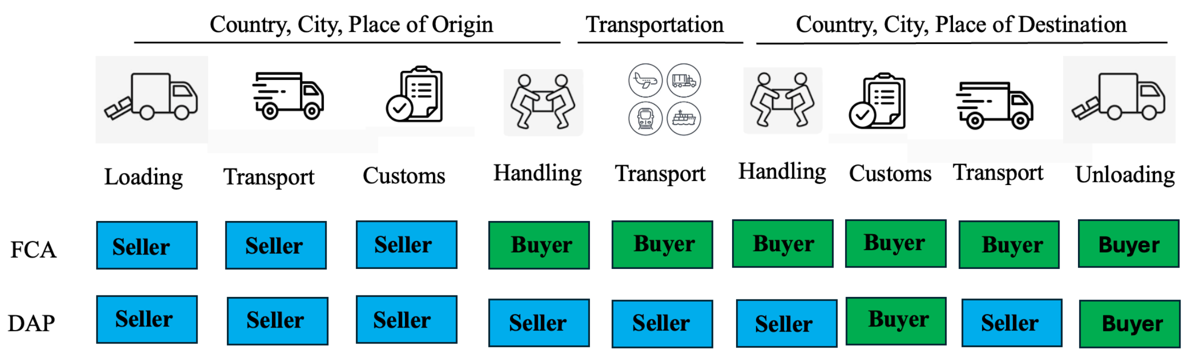

Figure 6. Division of responsibilities between buyer & seller for FCA and DAP Incoterms

Hence, in relation to most of its suppliers, FMC does not have control over how transport services are purchased and organised and how the suppliers prioritise between, for example, cost and CO_2 emissions. To change this situation, the logistics department at FMC is working with the procurement department to reverse the distribution, aiming to becoming responsible for the upstream transport for at least 80 per cent of its suppliers (FCA) and having suppliers in charge of only around 20 per cent of its upstream transport (DAP).

In cases where FMC is responsible for buying and organising the transport services, it uses contracts that are formed by FMC on a global level. 3PL A is currently the main global transport provider of FMC but FMC recently made a global decision to start using the transport services of 3PL B for 20 per cent of its total transport services. However, 3PL A remains as their main transport provider, being responsible for 80 per cent of FMC’s transport needs. Even though many decisions are centralised and thus made at a global, headquarters level, there are still opportunities for FMC in Sweden to initiate discussions with transport providers at the local and regional levels on reducing the climate impact. Such discussions have mostly focused on enhancing sustainability through more environmentally friendly transport options, which include less emitting transport modes, vehicles and fuels. In line with this, FMC recently started to investigate offerings from transport providers regarding less emitting transport services. For example, 3PL A has developed a ‘green’ transport solution as part of its initiative to contribute to a climate-smart transition to reach a fossil-free transport sector. To manage this, FMC and/or its contracted hauliers have invested in technologies supporting biogas, ethanol, bioDME and electricity in recent years. The ‘green’ solution means that 3PL A produces transport work equivalent to that generated by a shipment with fossil-free technology somewhere in the transport network. As well as 3PL A, 3PL B offers a similar green solution. FMC’s decision on using its transport providers’ green solutions for domestic road transport is under consideration by local management in Sweden. Other transport services depend on global decisions on the topic.

When FMC is responsible for buying and organising the transport (that is, FCA), it uses a transport management system (henceforth referred to as TMS). In this TMS, the supplier is responsible for booking the transport on behalf of FMC. The TMS allows the supplier to book one transport per purchase order and as many transport services as they want per day. The TMS also allows suppliers to change transport modes. Some such changes, which result in more emitting transport mode (for example, from sea to air), come with a system warning. This means it is possible for the supplier to impact on CO_2 emissions by choosing both more and less emitting transport modes. However, only around 60 per cent of the suppliers that use FCA use FMC’s TMS. The remaining 40 per cent of the suppliers that use FCA book the transport in a different TMS.

FMC’s enterprise resource planning (henceforth referred to as ERP) system currently records only the delivery date (the date goods arrive at FMC’s site in Sweden) but not the pick-up date; that is, the date when the goods leave the supplier. This makes it difficult to FMC to plan and control transport when it is responsible for it, because the company cannot see when shipments actually start or calculate accurate lead times. Having both pick-up and delivery dates is essential in order to understand and control the transport flow. The pick-up date marks the beginning of transport, while the delivery date marks the end. Together, they provide visibility of the transport timeline, allowing monitoring of delays, and ensuring that lead times can be planned according to customer needs. When suppliers manage the transport, this issue does not occur since they only need to provide delivery dates to FMC.

Although the procurement department primarily focuses on product/component procurement with a strong emphasis on cost and on lead time over sustainability, FMC is continuously working to identify areas to improve how transport is performed and its climate effects. Road freight from European suppliers and air freight from Asian suppliers are currently the most common transport modes. Express deliveries sometimes also require air transport but for regular deliveries FMC aims to reduce transport costs and improve sustainability, for instance by using sea transport instead of air. FMC uses statistics from its purchase orders (POs) to identify how to make transport more efficient, as it can offer insights into order patterns, shipment consolidation opportunities and logistics optimisation, as well as potentially reducing costs, cutting lead times and lowering emissions.

Collaboration with suppliers and internal business departments like the procurement and shipping departments is considered crucial for sustainability efforts to succeed. FMC works on sustainability audits with suppliers that also aim to identify opportunities for process optimisation, resource efficiency and reduction of carbon emissions in their supply chains. Additional efforts in this direction include sustainability audits with high-risk suppliers, as well as sending questionnaires to 4000 suppliers that help to assess their climate impact.

5.1.2 FMC's work with Scope 3 emissions

CO_2 emissions related to transport in the upstream supply chain are part of the Scope 3 emissions. FMC started reporting on Scope 3 emissions in its 2021 Sustainability Report and the reporting concerns two categories: (1) purchased goods and services and (2) transport and distribution. The company has an ambitious target of reducing its relative Scope 3 emissions from both categories by 30 per cent until 2030 based on the 2018 fiscal year. Scope 3 emissions represent the largest part of the company's total CO_2 emissions, comprising up to 99.98 per cent of total emissions.

In 2024, Scope 3 downstream emissions accounted for the vast majority of the emissions, as seen in Figure 7. Regarding upstream emissions the category of transport and distribution represented around 9 per cent of the total emissions, while the category of purchased goods and services accounted for around 91 per cent of the total emissions, as also shown in Figure 7.

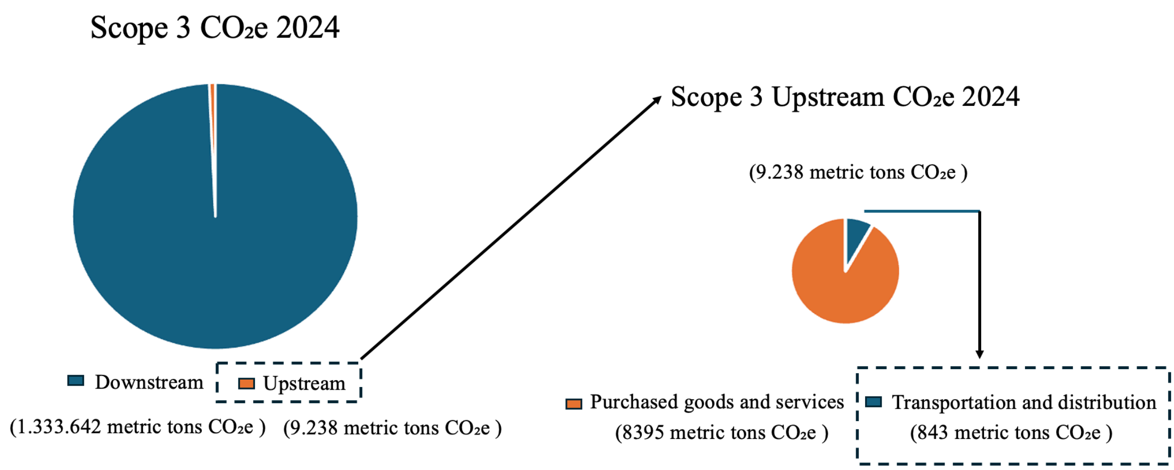

Figure 7. Total Scope 3 CO_2e 2024 (left) and Scope 3 Upstream CO_2e 2024 (right)

To clarify, the category of transport and distribution includes all transport purchased by FMC, both upstream and downstream. The purchased goods and services category includes all transport that is bought by the suppliers and 'embedded' in the offerings of the suppliers.

5.2 FMC initiatives aiming to reduce Scope 3 emissions

FMC is currently working on two initiatives that aim to reduce its Scope 3 emissions including transport-related emissions. The first one (referred to as Initiative 1 below) takes a broad view on reducing Scope 3 emissions, while the second (referred to as Initiative 2 below) focuses specifically on reducing transport emissions.

5.2.1 Initiative 1: Collaborating with suppliers to define and achieve common climate targets

FMC recently started an initiative to support their suppliers to reduce its own CO_2 emissions and, as a consequence, FMC's Scope 3 emissions. The initiative has two phases and addresses all Scope 3 emissions, transport-related emissions included.

Phase 1 started with the selection of suppliers to work with in this initiative. It was understood that FMC's most important suppliers already have climate ambitions and targets that are well defined and in progress. The idea of this initiative was to identify and work together with suppliers that could be impacted the most by this collaboration, meaning suppliers that still do not have well established sustainability plans. Initially, 20 Swedish suppliers were selected, based on how much FMC orders from them and the CO_2 emissions resulting from these orders. After an examination of the suppliers in the Decarbonisation Due Diligence Assessment (DDA), only six of these 20 suppliers turned out to have clear emission targets. The remaining 14 suppliers were further screened through checking their sustainability reports. Of those, 11 suppliers were chosen to become part of the initiative. These either did not have a sustainability report or had one that matched FMC's sustainability targets. This marked the end of Phase 1 and the beginning of Phase 2.

The selection of suppliers was to be followed by meetings and dialogues with the 11 suppliers. The discussions were to focus on how the suppliers could develop their sustainability plans and take actions to reduce their CO_2 emissions, and in turn FMC's Scope 3 emissions. The work is ongoing and so far only two meetings with one of these 11 suppliers have taken place, in January and May of 2025. The idea is to have meetings that have a collaborative and educational purpose, starting with explaining what the Scope 1, 2 and 3 emissions are, understanding whether the supplier has started to work towards reducing its emissions, identifying possible actions for the supplier to reduce its own emissions, how the supplier's emissions affect FMC, and how the supplier can contribute to reduce FMC's emissions.

The first supplier that FMC started to work with has yet to start developing a sustainability plan. The first meeting included basic sustainability concepts, explaining Scope 1, 2 and 3 emissions and allowed discussions on different alternatives regarding operational changes that can be implemented to reduce emissions, such as optimised usage of heating, ventilation and lightening, the use of renewable energy and waste management programmes. Regarding transport, although the supplier does not have a sustainability plan with pre-defined actions to reduce transport-related emissions, it does have sustainable actions in place, such as consolidating its deliveries once a week per region. The supplier is responsible for buying the transport services, which gives it the opportunity to make improvements, whether it is with less emitting vehicles or fuels. After the meeting, FMC and the supplier agreed that they had obtained valuable insights and agreed to have follow-up meetings every six months.

A follow-up meeting with the supplier took place in May 2025. The supplier reported that sustainability has started receiving higher attention from management. They are currently working on data collection on its processes and current emissions and data analysis. A follow-up meeting is planned in the beginning of 2026, when the supplier is going to present its preliminary findings on how to align to FMC climate targets and reduce its emissions.

After these initial meetings, FMC aims to continue with meeting the other 10 suppliers. The company also emphasised that it wants to work more closely with its suppliers, developing collaborative partnerships. FMC aims to get to a stage where the strategic buyers feel confident moving forward with the project, and to routinise continuous dialogues with suppliers that promote actions and results that are positive both for the suppliers and FMC in terms of CO_2 emission reduction.

5.2.2 Initiative 2: Reducing inbound transport-related emissions

Another FMC initiative aims to reduce 50 per cent of the company's inbound transport-related climate impacts by 2030, through (1) fewer shipments per supplier via shipment consolidation, (2) implementation of lead times that enable switching from air to sea freight, and (3) evaluation of changing Incoterms from DAP to FCA to take control of transport and thereby increase the opportunities to impact transport-related emissions. The project is a collaboration between the logistics and procurement departments, and it started in the beginning of 2025.

Phase 1 included a pre-study consisting of three steps: (1) a quantitative analysis of inbound transport and emissions, (2) a qualitative analysis of factors affecting consolidation, switch from air to sea freight and from DAP to FCA Incoterms, and (3) risk analysis and recommendations for process changes based on the results from Steps 1 and 2. Steps 1 and 2 of the pre-study were carried out by the Business Excellence team individual work, creating a project dashboard, putting the pre-study data together and presenting findings to the Steering Committee. The basis of the information used in these two steps was gathered from a Master's thesis conducted with FMC (Beronius & Andersson, 2023). The students calculated the transport emissions for two suppliers located outside of Europe, investigated how to change the transport mode from road and air transport to road and sea transport, and analysed the impacts of reducing the delivery frequency through consolidation. One of the suppliers uses FCA Incoterm and the other uses DAP. The supplier using DAP will be considered for switching to FCA. Step 3 was performed by the Business Excellence team together with the project team.

The Business Excellence department works as a team of internal consultants who are assigned to projects that have two or more collaborating departments from FMC that need other resources to help with the project management and execution. Four workshops were realised from February until May 2025 with the project team, consisting of two Business Excellence team members who are leading the project, together with the two project owners from the Shipping and Procurement Departments, respectively. Some of FMC's strategic buyers who are responsible for the supplier considered for a switch from DAP to FCA Incoterm also joined the workshops. So far, the workshops have focused on mapping the purchasing process, aiming to understand all of the steps of the process, including who is responsible for each step, which information is needed for each step, who needs to provide what information, and why this information is necessary. After the purchasing process is mapped,[5] recommendations will be made regarding how to reduce the number of shipments per supplier, how to adjust the lead time requirements so that these allow a switch from air to sea freight, and how to switch the Incoterms from DAP to FCA.

Regarding the reduction of the number of individual shipments per supplier, FMC's approach is to ask suppliers operating under FCA Incoterms to consolidate shipments twice a week in its TMS. This aims to improve transport efficiency by reducing shipment frequency and thereby lowering the associated emissions and costs. However, a corresponding risk analysis identified several potential challenges. First, shipment consolidation may increase the likelihood of delayed deliveries, as suppliers may be restricted to fixed consolidation schedules rather than shipping goods as soon as they are available. Second, reduced shipment frequency can lead to higher inventory levels at either the supplier or at FMC. Third, there is a risk related to supplier compliance and capability, as some suppliers may be unwilling to consolidate or lack the operational resources to proceed with the consolidation.

FMC is also considering adjustments to its TMS settings for one of its European suppliers to trigger road transport for smaller packages (under 70 kg) as a test. Usually, all such packages from European suppliers are delivered by air freight. In addition, the impact of switching transport mode from air to sea freight is also under investigation for a major supplier outside Europe. The accompanying risk assessment identified six challenges that may constrain the feasibility or success of this modal shift. First, there is a technical risk that unforeseen problems may occur during sea transport, preventing the transport mode from changed. Second, switching to sea freight carries the inherent risk that goods may not arrive on time, given longer transit times and potential schedule unreliability. Third, the there is a risk that packing requirements for sea freight may increase logistics costs, which can offset some of the financial benefits of a modal shift. A fourth risk concerns the logistics system itself, which may, under certain circumstances, automatically default to air freight; that is, in conflict with the planned adjustment. Fifth, the extended lead times required for sea freight may increase the occurrence of error codes within the order management system. Finally, the analysis highlights the inherent difficulty of predicting sea freight delays, given the influence of volatile factors such as port congestion, customs clearance, and weather disruptions, which collectively add reliability uncertainty in comparison with air freight.

[5] The process flow from signing a contract with a customer to paying suppliers is described in Appendix 1.

As part of its efforts to reduce transport-related climate impacts, FMC is evaluating the strategic implications of shifting the DAP to FCA as a standard. By adopting FCA as the default contractual arrangement, FMC would take greater control over the transport process, which would make it possible to implement measures aimed at improving efficiency, consolidating shipments, and reducing emissions. Therefore, FMC has initiated an investigation to assess whether establishing FCA as a standard practice across its supplier base is both operationally and commercially viable. The risk analysis associated with this potential transition highlights several important concerns. First, there is a legal risk related to incorrect FCA dates, which could lead to liability issues between FMC and its suppliers and customers. Second, switching to FCA might limit the company's ability to leverage competitive freight rates that could otherwise be secured under alternative contractual arrangements. Third, adopting FCA can result in lack of control regarding delivery dates. Fourth, there is a risk of invoicing complications. Fifth, risks may arise from the possibility that FCA is applied in countries or trade contexts where its use is inappropriate or non-compliant, potentially exposing FMC to administrative or regulatory complications.

For the Business Excellence team, the realisation of the workshops made it evident that the success of the project depends on enhanced collaboration between the procurement and shipping departments. This requires the establishment of clear channels of communication, a comprehensive understanding of each department's processes, and an increased awareness of their mutual requirements. Another lesson learned was the challenges in consistently identifying the appropriate audience to participate in the workshops. Several factors contributed to this, including the complexity of operating within a large organisation where it is not always evident who should be involved as well as overlapping responsibilities across departments.

At the end of Phase 1, recommendations were made regarding how to reduce the number of shipments per supplier, how to adjust lead times that allows to switch from air to sea freight, and how to switch suppliers' incoterms from DAP to FCA.

In order to reduce the number of shipments per supplier, shipment consolidation was identified as a suitable measure. An analysis of how such consolidation could be implemented in their ERP revealed that it would require a substantial amount of manual effort, making it operationally inefficient. Consequently, the recommendation was to request that suppliers consolidate their deliveries within the TMS twice per week. For the pilot implementation, two potential suppliers were identified as suitable candidates. With regard to extending lead times in order to facilitate a modal shift from air to sea freight, the recommendations were not only restricted to a modal shift but also incorporated a stricter control in the approval and reliance on air freight. Shipment consolidation was identified as an initial step in this direction. Two additional measures were proposed. The first was an adjustment of the TMS settings to increase the weight threshold for air freight shipments to 70 kg, thereby forcing a modal shift for these deliveries from air to road transport. The second was a targeted shift from air to sea freight for suppliers outside of Europe that currently account for a substantial proportion of the emissions.

As for potentially switching suppliers' Incoterms from DAP to FCA, the risk analysis indicated a considerable level of exposure, and the conclusion was that it would be necessary to make a well-informed and confident internal decision about how to address delivery terms in contracts.

Phase 2 was expected to start in May 2025, with the selection of 3–5 suppliers and the recommendations from Phase 1 were part of a pilot implementation that comprised three steps: (1) testing process changes with the 3–5 selected suppliers, (2) pilot evaluation, and (3) defining a concept to roll out process changes to other suppliers. Phase 2 started in August 2025, due to the need for extended time to finalise Phase 1 activities.

The shipment consolidation started with one supplier – shipments were consolidated for deliveries twice a week and the TMS settings were changed regarding the minimum weight that can trigger air freight. The plan is to extend these settings to a second supplier in the near future.

Changing air to sea freight for suppliers that currently account for a substantial proportion of emissions is under consideration for a Mexican supplier, but the implementation of this measure does not yet have a planned date, pending discussions between the procurement, logistics and legal departments to increase the confidence level and reduce risks.

5.3 Additive manufacturing and its impact on emissions

FMC is continuously improving its production methods, which has taken on an important role in their development and production of components and spare parts in recent years. FMC is primarily using AM to improve the products' technical performance. For some of FMC's products, AM allows the use of integrated design and production, which increases the functionality and performance of the 3D printed parts. Currently, CM and AM are used simultaneously, with AM counting for just a small portion of the production volume.

Although the introduction of AM at FMC was not motivated by the reduction of climate impacts, it has presented indirect positive effects on transport emissions. This section describes how FMC's efforts in AM, focusing on two components (A & B), have had consequences for the supplier network configuration and CO_2 emissions related to transport.

5.3.1 Supply Network Reconfiguration

The adoption of AM requires new materials, typically sourced from other suppliers than those used for the CM processes. Some materials that were used for CM are no longer necessary. Production steps are also eliminated or added. This shift triggers a reconfiguration of FMC supply network.

The structure of the supply network under both CM and AM is outlined below for Components A and B.

Component A

Component A has two parts: a front part with a complex design and a back part with a simpler and more standardised design. During periods of high workload, FMC sometimes outsources the production of the fully assembled Component A to an alternative supplier located in Sweden (Supplier C).

Conventional Manufacturing

Under CM practices, FMC sources the back part of Component A from a German supplier (Supplier A) and the front part from two different suppliers: one in India (Supplier B) and one in Sweden (Supplier C). The front part undergoes machining operations at FMC's workshop. After this, both the front and the back parts are sent to a Swedish supplier (Supplier D) for coating. Once coating is completed, the parts are returned to FMC's facility for the final assembly of Component A. Occasionally, when FMC is unable to produce Component A on time, it buys its final assembly from Supplier C.

Regarding the transport activities, the back part of Component A is delivered from Supplier A in Germany to FMC's production facility in Sweden using road transport (truck). The front part sourced from Supplier B in India is transported to Sweden by a combination of road and air transport, while the front part from Supplier C in Sweden requires local road transport. After machining at FMC's workshop, both parts are sent by road to Supplier D in Sweden for coating. The last leg of the transport chain is covered by road transport, when the coated parts are sent to FMC's facilities for final assembly.

Figure 8 provides a visual representation of the production and transport activities in the supply network of Component A under CM – including the CO_2 emissions for each transport activity.

Component A CM	*Casting*	Transport	*Machining* *FMC Sweden*	Transport	*Coating* *Supplier D Sweden*	Transport	*Assembly* *FMC Sweden*
Back part	Germany Supplier A	Road 0,045		Road 0,007		Road 0,007	
Front part (1)	India Supplier B	Air & road 4,198		Road 0,007		Road 0,007	
Front part (2)	Sweden Supplier C	Road 0,018		Road 0,007		Road 0,007	

Figure 8. Production & transport activities in the supply network - component A: CM

Additive Manufacturing

For AM of Component A, FMC sources 3D printing powder from either Supplier E or F in Germany. The back part continues to be purchased from the same Swedish supplier as in CM (Supplier A). FMC produces the front part in-house using 3D printing, with a build plate[6] sourced from Supplier G in Czechia. After printing, post-processing is carried out at FMC before the parts are sent to Supplier H in Germany for CT scanning.[7] Once scanning is completed, the parts return to FMC and are subsequently sent to Supplier D in Sweden for coating. The coated parts are then brought back to FMC, where the complete assembling of Component A takes place in-house.

The transport activities involved in the AM process start with the 3D printing powder from either Supplier E or F in Germany delivered to FMC in Sweden by road (truck). The back part from Supplier A in Sweden is also transported by road to FMC. The build plate from Supplier G in Czechia is delivered to FMC by road too. After post-processing, the printed parts are transported by road from FMC to Supplier H in Germany for CT scanning, then returned by road to FMC. Subsequently, the parts are

[6] A build plate is the flat surface on which a 3D printer or AM machine builds a part layer by layer.
[7] A CT scanning is the inspection and quality control tool for 3D printed parts.

sent by road from FMC to Supplier D in Sweden for coating and finally brought back by road to FMC's facility for assembling.

Figure 9 illustrates the supply network of Component A using AM.

Component A AM	*Casting/ powder production*	Transport	*Printing/ machining* *FMC Sweden*	Transport	*CT Scan* *Supplier H Germany*	Transport	*Transit* *FMC Sweden*	Transport	Coating *Supplier D Sweden*	*Transport*	*Assembly* *FMC Sweden*
Back part	Germany Supplier A	Road 0,045		Road 0,056		Road 0,056		Road 0,007		Road 0,007	
Alternative 1 Powder	Germany Supplier E	Road 0,095		Road 0,056		Road 0,056		Road 0,007		Road 0,007	
Alternative 2 Powder	Germany Supplier F	Road 0,072		Road 0,056		Road 0,056		Road 0,007		Road 0,007	

Figure 9. Production & transport activities in the supply network - component A: AM

Component B

Conventional Manufacturing

While using CM, casts are supplied by one of four suppliers: Supplier I and J in the UK, Supplier K in Italy and Supplier L in Sweden. The selection of the supplier is decided based on FMC's needs and the suppliers' available capacity. Two suppliers – Supplier M in the UK and Supplier N in Sweden – are responsible for the next step: machining. After the machining, the parts have holes drilled in FMC. Following this is the coating, which is provided by three different suppliers: Supplier O in Ireland, Supplier P in Germany or Supplier Q in Italy. Once the parts are returned to FMC's production site, Component A is assembled in-house.

Regarding transport, Supplier I in the UK, Supplier K in Italy, and Supplier L in Sweden, deliver casts by road (truck) to FMC. Supplier J, in the UK, delivers casts by air and by road to FMC. After the parts are printed at FMC, they are sent for machining from FMC to Suppliers M in the UK and Supplier N in Sweden by road. After the machining is completed, the parts are returned by road to FMC. For coating, FMC sends the parts to Supplier O in Ireland by road and air and to Supplier P in Germany and Supplier Q in Italy by road. The coated parts are returned to FMC for assembling using the same transport modes.

Figure 10 illustrates the supply network of component B when using CM

Component B CM	*Casting* *Alternative Suppliers*	Transport	*Machining Transit* *FMC Sweden*	Transport	*Machining* *Alternative Suppliers*	Transport	*Drilling* *FMC Sweden*	Transport	*Coating* *Alternative suppliers*	*Transport*	*Assembly* *FMC Sweden*
	UK Supplier I	Road 0,130		Road 0,120	UK Supplier M	Road 0,120		Road & Air 1,185	Irland Supplier O	Road & Air 1,185	
	UK Supplier J	Air & Road 1,180		Road 0,014	Sweden Supplier N	Road 0,014		Road 0,075	Germany Supplier P	Road 0,075	
	Italy Supplier K	Road 0,170						Road 0,130	Italy Supplier Q	Road 0,130	
	Sweden Supplier L	Road 0,008									

Figure 10. Production & transport activities in the supply network - component B: CM

Additive Manufacturing

When AM replaces CM for Component B, the casting activity is replaced by 3D printing in-house and the step of drilling is eliminated, as the printing process includes the holes in the component manufacturing. The parts are 3D printed on the top of a build plate, after which there are some post-processing machining activities. The part then undergoes heat treatment at one of three suppliers: one in Germany (Supplier R) and two in Italy (Supplier S and Supplier T). After heat treatment, the part is returned to FMC, where a control check is performed. If it passes inspection, it is sent to one of two coating suppliers (Supplier D in Sweden or Supplier Q in Italy). After coating, the part comes back to FMC for final in-house assembly of the component.

For transport, the same two German suppliers (Supplier E and Supplier F) used for Component A provide the printing powder, which is delivered to FMC by road. After printing and machining at FMC, parts are sent for heat treatment by road to one of three suppliers: Supplier R in Germany and Suppliers S and T in Italy. Heat-treated parts are shipped to FMC by road, where there is a control check. Parts are then sent for coating by road to one of two suppliers: Supplier D in Sweden and Supplier Q in Italy. Coated parts are also returned by road to be assembled at FMC.

The 3D printed version of Component B requires a production process with more steps, with additional activities and suppliers. See Figure 11 for an illustration of the supply network of Component B when produced with AM.

Component B AM	*Powder production* *Alternative Suppliers*	Transport	*Printing and machining* *FMC Sweden*	Transport	*Heat Treatment* *Alternative Auppliers*	Transport	Control FMC Sweden	Transport	Coating *Alternative suppliers*	*Transport*	*Assembly* *FMC Sweden*
	Germany Supplier E	Road 0,095		Road 0,079	Germany Supplier R	Road 0,079		Road 0,007	Sweden Supplier D	Road 0,007	
	Germany Supplier F	Road 0,072		Road 0,130	Italy Supplier S	Road 0,130		Road 0,13	Italy Supplier Q	Road 0,13	
				Road 0,110	Italy Supplier T	Road 0,110					

Figure 11. Production & transport activities in the supply network - component B: AM

5.3.2 Upstream transport CO_2 emissions calculations

Regarding carbon emissions when using CM and AM, all the possibilities of supplier combinations were considered for Components A and B. Component A has three possible supplier combinations for CM and two for AM.

In the situation where Component A is produced by using CM, the supplier combinations provide a range of carbon emissions from a minimum of 0.076 kg CO_2e per tonne to a maximum of 4.257 kg CO_2e per tonne. The highest emissions results from using air freight from Supplier B located in India. When AM is applied to produce Component A, the calculated carbon emissions range from 0.242 kg CO_2e per tonne to 0.265 kg CO_2e per tonne. This suggests that AM can result in lower CO_2 emissions compared to CM methods for Component A. The emissions resulting from different supplier combinations depend on the suppliers' locations and their choices of transport modes. This can be noted especially for CM.

In the situation where Component B is produced by using CM, there are 24 possible supplier combinations and 12 when using AM. The resulting emissions for Component B are more varied, particularly for CM, considering there are 24 possible supplier combinations. The carbon emissions for CM of component B varies from a minimum of 0.186 kg CO_2e per tonne to a maximum of 3.578 kg CO_2e per tonne. For AM production of Component B, there are 12 supplier combinations, with emissions ranging from 0.241 kg CO_2e per tonne to 0.615 kg CO_2e per tonne.

Table 4 shows the lowest and highest CO_2e (per tonne) emissions for Components A and B, respectively, for both production methods.

	Component A CM	Component A AM	Component B CM	Component B AM
Lowest CO_2e per tonne	0.076 kg	0.242 kg	0.186 kg	0.241 kg
Highest CO_2e per tonne	4.257 kg	0.265 kg	3.578 kg	0.615 kg

Table 4. CO_2e (per tonne) emissions for component A and B

6. Analysis

This section is divided into two parts. The first addresses the two initiatives taken by the case company, and the challenges and potentials that they have identified so far. The second part focuses on the case company's experiences of AM and its consequences in terms of supply network reconfigurations and the transport emissions following these reconfigurations.

The analysis of the two initiatives, as well as the introduction of AM, highlights both the opportunities and challenges associated with reducing transport-related CO_2 emissions in the case company's upstream supply chain. It also illustrates that both intra- and inter-organisational interaction play critical roles in these endeavours.

6.1 Analysis of the initiatives

Both initiatives show that significant emission reductions can be achieved through the reconfiguration of supply networks, particularly through two complementary approaches: (1) consideration of supplier location, which can contribute to reduce transport distances and emissions, and (2) lead time management, which can help to shift transport mode to lower-emission alternatives, which helps reduce the emissions. Initiative 1 demonstrates the potential of supplier collaboration to implement low-carbon practices and achieve sustainability goals. Initiative 2 shows that internal alignment between departments (functions) is key to make projects successful and that operational adjustments, such as consolidating purchasing orders and limiting air freight, can reduce emissions without compromising service levels, provided that careful planning and risk management are in place.

Initiative 1 reflects FMC's proactive approach to Scope 3 management through supplier collaboration. It highlights the importance of targeted engagement, capacity building, and continuous dialogue in driving sustainability across the supply chain. The initiative is divided into two distinct phases and includes all categories of Scope 3 emissions, including those related to transport. It has had a good start and is to be rolled out in Phase 2 to the other 10 suppliers selected by the procurement team. The plan is to use the experience with the first supplier to develop a standardised process on how to approach the suppliers in a collaborative way to develop relationships that will support both parties in reducing their CO_2 emissions. The overall strategy of this initiative not only supports FMC's climate target but also contributes to an industry transformation by helping suppliers with limited sustainability knowledge and infrastructure.

Initiative 2 demonstrates a multi-dimensional approach to transport-related emission reduction, integrating operational, technical and behavioural strategies. The phased structure allows for iterative learning and risk mitigation, while the importance of internal collaboration reflects the systemic nature of sustainability transitions.

On an operational level, it is relevant to note that FMC has a considerable lead time regarding deliveries to their customers, around 9–10 months. Hence, it seems realistic to expect that it would be possible to work around the lead time to their component suppliers. This, in turn, would allow switching transport mode from air to sea freight, which would reduce their transport-related CO_2 emissions.

Some changes on a technical and behavioural level are also possible. For example, the use of air freight is sometimes due to putting purchasing orders separately in their ERP and TMS systems. In most cases, this automatically triggers air freight. One possible solution could be to disable the choice of air freight for European shipments in their TMS, just allowing suppliers to book air freight under exceptional conditions agreed in advance with FMC. Consolidating purchasing orders would also enable sea freight. However, switching to sea freight has an impact on the lead time and it requires more activity planning and coordination, as well as risk analysis; if a customer has a delay on receiving a product, this can have a huge financial impact, and it could cost FMC the loss of a customer.

FMC could consider how these initiatives interplay with other purchasing and supply decisions to be able to reduce their transport-related emissions in collaboration with their suppliers by aligning sourcing practices, logistics planning, and supplier engagement to enable more sustainable transport choices and foster long-term emissions reductions.

The initiatives point at several organising challenges – both internally, within the firm, and in relation to the suppliers. The intra-organisational challenges include how to identify the 'right' internal actors to involve in the initiatives. The inter-organisational challenges concern both supply base issues, including the choice of suppliers to involve in the initiatives, and how to relate to individual suppliers. The connections between the intra- and inter-organisational challenges also concern the extent to which the processes can or should be standardised (that is, for all suppliers) or how these can be specifically adjusted to different potentials in relation to different suppliers. Moreover, the links between firm-internal and external activities also depend on the system support as illustrated by the ERP system and the TMS. Adaptations of these two systems can be made to 'force' activity adjustments with a positive effect on the emissions. One such example is changing the minimum weight for air freight in the TMS, forcing packages that weigh less than the pre-defined weight to be delivered by road.

In view of the strategic purchasing issues, the initiatives relate to all three. Changes in Incoterms affect the division of responsibilities in terms of who is in charge of buying the transport services. By assuming responsibilities for these purchases, the buying firm can also identify and leverage opportunities to reduce emissions through engagement with their suppliers on modal shifts and other potentials associated with lead time adjustments. Regarding supply base issues, the initiatives entail consideration of 'emission-related categorisation' of the suppliers and of ambitions to learn how to interact with different suppliers on these matters.

6.2 Analysis of supply network effects of using AM

The case illustrates how AM has the potential to affect upstream transport emissions. First, the supply network was reconfigured in such a way that several component suppliers could be replaced by raw-material suppliers although in both component cases some of the previous suppliers remained. For Component A, the most distant supplier could be replaced when AM was applied, which had a major impact on the carbon emissions since air freight was used in this case. However, the lowest carbon emissions were found in one of the supplier combinations used for CM. Second, the chain of production and transport activities was altered: some production activities previously carried out by suppliers were replaced by AM at the buying firm, while other production activities (such as heat treatment) were added. Still, a large share of the production (in terms of cost) was moved in-house in both cases which relates to previous findings of a higher level of vertical integration for AM (Oettmeier & Hofmann, 2017). Third, because of the altered chain of production activities, the transport activities were also affected. In both cases, a set of transport activities could be eliminated, while other transport activities were added. The need to add transport activities was a result of new production activities being carried out by specialised suppliers.

For both components, the outcome in terms of transport-related emissions points to a need for a comprehensive case to case activity level analysis of production processes and supplier selection as the sequence of activities and the location of suppliers, together with the transport modes used, were decisive for the outcome. As illustrated for Component A, the calculations suggest that the use of AM has the potential to reduce CO_2e per tonne and the supplier combination was decisive for the outcome.

For FMC, the use of AM is still not applied on a large scale and several steps in the production process might be eliminated once this method has been completely tested and proved. This means that the use of AM, with less production activities carried out by distant suppliers, could result in a reduction in transport demand and thus further reductions in terms of CO_2e per tonne. However, these potential effects do not appear 'automatically' from a change from CM to AM; they require scrutiny at the activity level of analysis.

As other studies have recognised (e.g., Ronchini et al. 2023; Singh et al. 2023), the motives for replacing CM technologies with AM are not mainly related to reducing the transport emissions, although that can become considered as one of several possible positive outcomes. Moreover, the case illustrates that assumptions on how AM may shorten and simplify supply chains/networks (Oettemeir & Hofmann, 2017; Friedrich et al., 2022; Singh et al. 2023) are not always valid. In contrast, the entire sequence of production activities, in addition to the actual 3D printing, needs to be included in the analysis in order to be able to analyse the consequences for the transport activities and the emissions these result in.

The transport modes identified in the case are the ones that are currently used for deliveries from suppliers. The possibilities for modal shifts due to less time restraints for AM (Verboeket & Krikke, 2019; Akbari & Ha, 2020; Friedrich et al., 2022; Kunovjanek et al., 2022) could not be captured in the case. If or when transport emissions become a priority, there may be potentials in, for instance, replacing road with rail or sea freight for some distances. Also, better utilisation of vehicles (such as increasing the fill rates) relate to time constraints, which is an area in which data could not be captured in the case study but could be a source of improvements.

The case company's use of multiple sourcing for several production activities makes the supply network configurations difficult to overview and the outcomes of using different combinations of suppliers differ extensively when comparing CM with AM.

To summarise, the introduction of AM led to significant changes that can be analysed through three primary dimensions: (1) supply network reconfigurations, (2) the chain of production and transport activities, and (3) transport activities and their climate impact.

Regarding supply network reconfigurations, the implementation of AM triggered re-structuring of the supply base. Suppliers of some parts were consolidated into a few raw material suppliers for the printing powder while other suppliers, used for CM, were retained for both components. Particularly for Component A, the integration of AM made possible the elimination of the most geographically distant supplier, with positive effects on both CO_2 emissions and lead times.

Regarding the chain of production activities, the adoption of AM resulted in shifts in the production activities' location. Certain manufacturing processes that were previously outsourced to suppliers were replaced by in-house production at FMC. Simultaneously, new production activities, such as heat treatment, were introduced to the chain of production activities.

The introduction of AM impacted on the transport activities, as the changes in the sequence and location of production activities had effects on transport requirements. The elimination of certain suppliers led to a cut of associated transport activities. However, the introduction of new production steps created a need for additional transport activities. This reconfiguration thus impacted on the transport activities embedded in the supply network and had implications for overall CO_2 emissions, lead times and logistics costs.

The analysis of the effects of using AM in contrast with CM also indicates changes across all three purchasing issues. First, replacing CM with AM suggests a change in the division of labour between the buying firm and its suppliers. The literature on AM suggests that increased vertical integration leads to shorter and simpler supply chains, which reduces the demand for transport activities. However, the case demonstrates that these effects are far from straightforward, as the adoption of AM may introduce additional production activities, which in turn can increase transport requirements. This highlights the need for activity level analysis to accurately assess the impact of AM on transport-related emissions. Second, the supply base is affected by use of AM. Currently, AM and CM are used in parallel, which results in an expanded supplier base, as certain suppliers are specific to CM while other to AM. Third, the case also points to the complexity associated with implementing multiple sourcing strategies across a wide range of production activities. This complexity entails challenges in analysing the implications of changes to the supply base and complicates the management of individual supplier relationships.

7. Concluding discussion

To recapitulate, the aim of this study was to explore how buying firms can reduce the transport-related climate impacts from their upstream supply chains and the main challenges and opportunities in doing so. This chapter starts with a reflection on the research questions, then elaborates on the findings of this study and discusses three themes for further exploration; (1) how to identify the right measures to take?, (2) how to analyse the effects on transport emissions of different measures?, and (3) how to organise internal and external networks to capture the opportunities and tackle the challenges? The chapter ends with topics for future research.

7.1 Reflecting on the research questions

To approach the aim of the thesis two broad research questions were formulated:

RQ1: How can buying firms reduce transport emissions in their upstream supply chains?

RQ2: What are the main challenges buying firms face in their attempts to reduce transport-related climate impacts within their upstream supply chain?

Reducing transport-related emissions in upstream supply chains has become a critical concern for buying firms seeking to align their operations with global sustainability goals. Chapter 2 provides an understanding on how firms can address this issue through strategic decisions across five interrelated areas: supplier base and location, lead time requirements, production methods, transport modes, and vehicle and fuel choices.

One of the most impactful ways to reduce these emissions involves the geographical reconfiguration of the supplier base. Empirical evidence shows that sourcing from geographically closer suppliers can significantly reduce transport distance and associated CO_2 emissions. Nearshoring, for instance, has proved relevant reductions in inbound transport emissions. Despite the clear environmental benefits, many firms still fail to acknowledge their responsibility for upstream freight emissions, often due to the absence of mandatory reporting standards. Integrating environmental considerations into supplier selection and fostering collaborative relationships with suppliers are essential steps toward reducing emissions. Such collaborations enable shared logistics planning, route optimisation, and shipment consolidation, all of which contribute to lower transport-related emissions.

Lead time requirements also play a key role in reducing transport emissions. Short lead times often require the use of urgent shipment methods, particularly air freight, which is the most carbon-intensive transport modes. Studies have shown that air freight can emit up to 47 times more CO_2 per ton-mile than sea freight. Conversely, flexible lead time policies allow the adoption of slower, more sustainable transport modes and facilitate shipment consolidation and better vehicle utilisation. Therefore, managing lead time variability is crucial for aligning operational efficiency with environmental objectives.

Production methods, particularly the shift toward decentralised and digitally enabled manufacturing, offer further opportunities for emissions reductions. AM and Industry 4.0 technologies such as Internet of Things (IoT), artificial intelligence (AI) and blockchain enable localised production, simplified supply networks, and reduced material flows. These innovations not only potentially reduce the number of suppliers and transport stages but also enhance logistics efficiency through real-time data and predictive analytics. By reconfiguring supply networks and enabling production closer to end users, these technologies could contribute to shorter and more sustainable supply chains.

The selection of transport modes is another critical determinant of supply chain emissions. Road and air freight are significantly more carbon-intensive than rail and maritime transport. Electrified rail systems, in particular, offer substantial opportunities for decarbonisation. While modal shifts are recognised as effective strategies for reducing emissions, their implementation is often limited by infrastructural and operational barriers. Intermodal and multimodal transport solutions can help overcome these barriers, although their effectiveness will vary depending on route and context, for example.

Finally, vehicle technology and fuels type directly influence the carbon intensity of transport operations. Transitioning to energy-efficient vehicles and low-carbon fuels such as electricity, hydrogen, and biodiesel can lead to emissions reductions. However, the success of these transitions depends on factors such as the carbon intensity of the local energy grid, infrastructure availability, and operational practices. Regular vehicle maintenance and technical upgrades further enhance fuel efficiency. Collaboration with suppliers and transport service providers is essential to support the adoption of sustainable vehicles and fuels. By working closely with them, buying firms can align their sustainability goals with operational capabilities, share the financial and technical burden of transitioning to greener technologies and ensure a more efficient and sustainable supply chain.

The study reported in this thesis has identified several challenges that buying firms face in their efforts to reduce transport-related climate impacts.

A large number of goods and transport service suppliers and the embeddedness of transport activities in supply networks complicate efforts to reduce transport-related emissions. A strategic supplier selection that balances environmental goals with cost and quality issues therefore becomes a multifaced challenge.

Operational pressures to meet short lead times often conflict with environmental objectives. For example, using urgent shipping can attend customer requirements, but it increases emissions. Being more flexible about lead time requirements to be able to use less emitting transport modes may affect service levels and customer satisfaction. Firms need to navigate this trade-off in a way that reduces transport-related emissions and still fulfils service requirements of customer.

There are also technological and organisational barriers. The adoption of decentralised production and digital technologies requires substantial investment and organisational change. Firms may lack the technical capabilities or resources to implement these innovations in an effective way. Moreover, effective emission reduction strategies depend on collaboration and data sharing across organizational boundaries, which still remains a challenge.

Buying firms are also facing increasing regulatory pressure to address transport-related climate impacts within their upstream supply chains. Under the evolving EU regulatory landscape, the CSRD requires comprehensive disclosure of Scope 3 emissions, which include transport activities. Furthermore, the ETS 2 introduces carbon pricing for road transport fuels, effectively increasing the cost of emissions associated with upstream logistics. These costs are likely to be transferred to buyers through higher transport service charges.

It can be concluded that while there are multiple pathways for buying firms to reduce transport-related emissions in their upstream supply chains, these efforts are hindered by systemic challenges that require coordinated action, investment and policy support. An integrated approach that considers the interdependencies among supplier location, lead time, production methods, transport modes and vehicle and fuel choices is key for designing resilient and low-carbon supply chains and achieving meaningful climate impact reductions.

7.2 How to identify the right measures to take?

To reduce transport emissions embedded in their supply networks, buying firms need to consider – and, in some cases reconsider - the structure of their supply networks. Hence, the range of measures that can be taken to reduce the transport emissions upstream can broadly be divided into those that can be implemented in current supply network configurations and those that require supply network reconfiguration.

Some measures can be taken without reconfiguring supply networks, or by involving product and transport suppliers; transport-related emissions can be reduced by demanding sustainable transport solutions from suppliers (Koh et al., 2023) – when they are responsible for the transport (e.g. Incoterm DAP) and from transport service providers (Ferre & Thomé, 2023), when the buying firm is responsible for the transport (e.g. Incoterm FCA). However, it is important to recognise that while alternative fuels and advanced vehicle technologies offer significant emission reduction potential, their widespread adoption faces several challenges. These include higher upfront costs, limited refuelling or charging infrastructure, and the need for supportive policy frameworks (Dimitriadou, 2023). Moreover, the environmental benefits of alternative fuels can vary depending on their production pathways. For example, biofuels derived from waste or sustainably managed crops can offer substantial carbon savings, while those produced from conventional crops may have a more ambiguous climate impact due to higher land-use emissions.

Through collaboration between buying firms and their suppliers, buying firms could better understand and manage the environmental impacts of their purchasing behaviour. This collaboration could foster partnerships to help both parties reduce their transport-related emissions. For example, many firms have sustainability reports that show their current emissions and emissions targets and a code of conduct that states how suppliers are expected to reduce their transport-related climate impacts. Hence, working towards partnerships with suppliers could allow identification and implementation of best practices on low carbon technologies or emissions metrics.

There is a complex interaction between lead time requirements and transport emissions, which shows the importance of strategic planning and management in supply chains to balance efficiency and environmental impacts (Li et al., 2019). The re-evaluation of lead time requirements can help buying firms to improve their logistics operations and reduce transport-related emissions (ibid).

Regarding measures that require supply network reconfiguration, acknowledging that supplier location has considerable impact on transport-related emissions, buying firms can reduce transport distances by prioritizing suppliers located in closer geographical proximity to their production facilities, potentially reducing the carbon footprint associated with their inbound logistics (Sarioğlu, 2023).

Production methods are closely linked to the reconfiguration of supply networks, particularly through their influence on transport-related emissions. Decentralized production has long been recognized as a strategy to reduce transport distances and emissions (Böge, 1993), and this has gained renewed relevance with the rise of AM and digital supply chain technologies. Recent studies (Wang et al., 2024; Forge, 2025) show that even small shifts in CM, such as local sourcing, can significantly reduce transport emissions. AM exemplifies this by enabling supply network reconfiguration – simplifying product design, reducing material types, and minimising the number of suppliers (Ford & Despeisse, 2016; Gibson et al., 2021). Industry 4.0 technologies, like IoT, A I and blockchain further enhance this transformation by optimizing logistics, improving transparency and reducing unnecessary transport (Anthony et al., 2024; 2025; Ojadi et al., 2025).

The findings in this thesis highlight that a path toward lower transport-related emissions is multi-dimensional, with a combination of strategic supplier selection, internal capability development, operational planning and technological innovation. Short-term progress can be achieved with operational improvements in procurement practices, supported by stronger cross-functional collaboration. Long term opportunities lie in the reconfiguration of supply networks, e.g. by use of AM, which can reshape transport flows. Ultimately, transport emission reductions will require balancing efficiency, risk and sustainability goals through an integrated and adaptative PSM strategy.

7.3 How to analyse the effects of different measures?

Analysing the effects of measures aiming to reduce upstream transport emissions requires a subtle understanding of how transport activities are embedded in supply networks. These networks are shaped by both vertical interdependency – where activities are sequentially linked across firms – and horizontal interdependence, which refers to the reliance on shared resources for the execution of activities (Thompson, 1967; Richardson, 1972; Dubois et al., 2004). Such interdependencies introduce complexity that influences both the configuration of supply networks and the coordination of activities within them.

Although transport activities are seldom explicitly addressed in conceptualisations of supply networks (Eriksson et al., 2022), they play a critical role in linking geographically dispersed production activities. Hence, transport activities can be identified between the production activities carried out by the suppliers and the buying firms, and thus link to the sequence of production activities. The characteristics of these transport activities, such as distance, modal choice, and timing, are shaped by the geographical location of suppliers and their upstream supply chain (Böge, 1995) as well as by lead time requirements that result from the coordination of sequentially interdependent production processes (McKinnon, 2016; Rogerson, 2016)

The sequence of production and transport activities thus relates to the supply network configuration. However, since the conceptualisation of supply network configurations typically relies on how buyer-supplier relationships are related to one another (see e.g., Lambert & Cooper, 2000), the sequence of activities may divert from this structure, which, in turn, impact on how transport activities are organised in the supply network. In addition, transport service providers may be either first or second tier suppliers, when first tier suppliers of e.g. components, take charge of buying the transport services. Hence, the TST consisting of the buyer and supplier of goods, and the transport service provider - involved in a business relationship with one of them - thus complicates the matter (Andersson et al., 2018). To capture the effects of supply network reconfigurations on transport activities there is a need to inquire into how the production activities coordinated through business relationships with suppliers of products (e.g., components, raw materials) become affected, and how transport activities relate to this coordination.

Thus, to assess the impact on transport emissions of reconfiguring supply networks when a buying firm reconfigure their supply networks, the following needs to be analysed:

- The change of the chain of production and transport activities, the interdependence between them, and how the activities are coordinated
- The transport activities that are eliminated or modified and their climate impact
- The transport activities added and their climate impact

While transport is embedded in every stage of a supply chain, and every stage of production relies on timely deliveries, transport activities and other activities in supply chains are often subject to ‘loose couplings’ since transport arrangements are handled by external logistics and transport providers (Browne et al., 2023). Logistics service providers (LSPs) combine transport activities across supply chains of many combine transport activities across supply chains of many customers (or shippers), without involving them in the coordination. Also, other logistics services such as warehousing can be included to satisfy their customers' needs without making them aware of how the actual transport activities are carried out. In addition, transport services are often integrated in suppliers' product offerings so that the transport activities are not visible to their customers (Eriksson et al., 2022). All this entail that efforts to identify and reduce transport emissions is challenging for individual supply network actors. These difficulties also impact on efforts to analyse the consequences of making different changes.

An analysis must therefore identify critical links between transport and other activities in the supply network, including production activities of the firms involved. This requires attention to both vertical and horizontal interdependencies (Dubois et al., 2004). Furthermore, different combinations of units of analysis are needed to capture the embedded nature of transport activities. For example, transport activities can be analysed in terms of how they are linked to products (Böge, 1995), or by focusing on supplier relationships and the coordination of production and transport activities. Such analyses enable the identification of potentials in, and the conditions for, interaction between companies to reduce transport emissions

7.4 How to organise internal and external networks to capture the opportunities and tackle the challenges?

In view of the TST, there is a difference between the situation where the product supplier takes on the transport service procurement and where the buying firm does. When the supplier of products takes on the buying of transport services, two internal firm functions are key in situations where transport services are subject to change: the transport purchasing function and the function in charge of buying the products; that is, the goods subject to transport. When the buyer of products takes on the buying of transport services the interaction on transport services need to involve the product suppliers who are also buying the transport services. Moreover, in these cases the product supplier may involve its transport provider(s) in the interaction. Also, interaction with other firm-internal functions such as for example production, logistics, sustainability and product development may be needed to address some of the possible actions to reduce transport carbon emissions (see Figure 12 for an illustration). This is in line with the conclusions of a recent systematic literature review which stated that in order to diffuse sustainability throughout a supply network "cross-functional collaboration between departments, joint development and co-creation with suppliers and collaboration with external stakeholders" is essential (Miandar et al., 2024, p. 518).

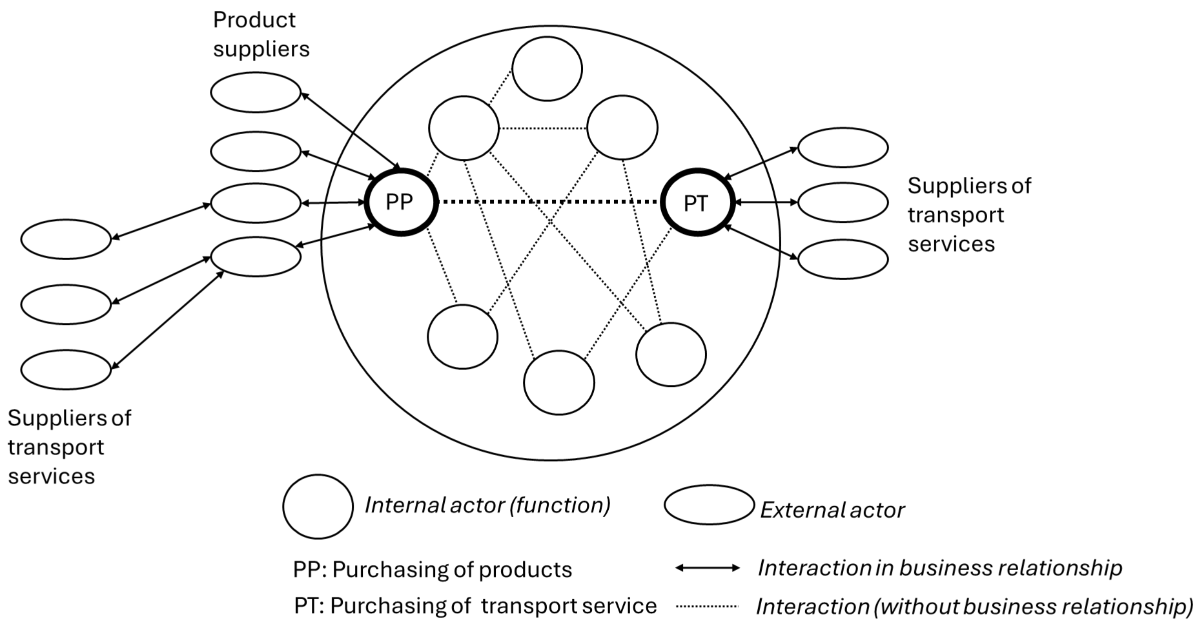

Figure 12. Internal and external interaction

General ‘rules’ usually apply in situations characterised by ‘given’ transport needs, such as in terms of distance and delivery time, and/or based on the transport service providers’ standardised offerings. Below, some of the measures to reduce transport emissions described in the literature are linked with different types of actors that may need to interact to make the adjustments and adaptations needed.

I. *Longer lead times*: One type of measure discussed and analysed in previous research regards potentials in allowing longer lead times, thus enabling more sustainable transport. One example is shifting transport mode, for example from air to sea, or so-called slow steaming, allowing for ‘slower’ transport with fewer emissions. Another example is allowing for better resource utilisation, such as increasing the fill rates in trucks (McKinnon, 2016; Rogerson, 2017). In these situations, adjustments are needed in the production planning, which requires interaction with the production and logistics functions as well as the product supplier and the supplier of transport services. In some situations, a way to deal with the issue may be for the product suppliers to set up vendor-managed inventories (VMI) to enable ‘slower’ and more sustainable transport modes or full truck loads while permitting the buying firm access and relax demands on its planning.

II. *Choice of product suppliers and locations*: Another type of measure is to address the choice of product suppliers and/or the location of warehouses and terminals used to capture distance related aspects (see e.g., Liotta et al., 2015). When multiple sourcing (concerning product suppliers) is applied, a focus on reducing the transport emissions may favour single sourcing wherein the distance and lead time aspects may also be a starting point for developing the business relationship with the product supplier to allow for more sustainable transport solutions. These situations involve both the purchasing functions (the one buying products and the one buying transport services) as well as the logistics function and may also require adaptations that necessitate involvement of the product development function.

III. *Emission reduction demands on transport services*: Interaction with suppliers of transport services may result in adaptations of the general policies for transport services across a range of product supplier relationships (see e.g., Evangelista et al., 2018). When such general measures are contemplated, analysis of their impact on individual product supplier relationships in terms of adaptations and adjustments are needed since their effects may not be known in advance. Hence, interaction is needed with a range of external suppliers (both of products and of transport services) as well as the two purchasing functions (products and transport services).

The three types of measures to reduce transport emissions point to different interaction patterns. Delving further into how these and other measures are addressed in terms of interaction patterns in the continuing case study will also enable scrutiny of the content of the interaction between the involved actors.

Many firms categorise their purchases to capture different features of the products and services and to address different challenges and opportunities. Thus, the division of purchasing specialists typically relate to product and/or supplier features and not to the products' influence on the transport needs, nor of the transport service features. Hence, to capture potentials in transport emission reductions, other categorisations are needed. Such categorisation might be a starting point for internal interaction among company functions on how to proceed to explore different potentials and what suppliers that need to be involved.

Apparently, there are several interrelated units of analysis to consider when analysing the transport activities embedded in the supply network of a buying firm. First, the products and how these relates to transport service features need to be considered. Second, the deliveries/transport missions and their features in terms of transport mode(s), frequency, distances etc. are important issues. Third, the business relationships with product suppliers and transport service providers need to be considered. Fourth, the 'geography' of suppliers, warehouses, ports etc. are important aspects.

Taking a starting point in specific goals to reduce transport emissions, as exemplified by the case company in this study, may be useful to identify what transport services that are most problematic and then relating these to individual supplier relationships and to TSTs. Interaction among these actors focusing on different ways to reduce the transport emissions may result in solutions that can be applied in other similar situations and/or connected TSTs. For instance, individual transport service providers may be involved in several product supplier relationships but in different roles and based on different contracts.

The continuing case study will address these issues by following the case company's efforts to find ways to reduce its transport emissions by making firm-internal functions and external suppliers interact. The types of measures and 'situations' in terms of interaction patterns are problematic in that certain interaction patterns are required to identify suitable measures e.g., to prolong lead times to allow for more sustainable transport modes, while other interaction patterns may be needed to explore and implement such measures.

Interaction between previously non-interacting parties seems needed to analyse and act upon different measures to reduce transport emissions in supply networks. However, all actors cannot interact about all measures and therefore identification and further exploration of how certain interaction patterns relate to certain measures may be valuable for practice as well as research.

7.5 Future research

While this study has contributed to the understanding of the phenomenon of how buying firms can reduce transport-related climate impacts in their upstream supply chain, it has also opened avenues for further research on the topic.

Building on the present work, future studies could delve into (1) the analysis of firm-internal and external interaction to reduce transport emissions in upstream supply chains, (2) how changing Incoterms from DAP to FCA can help buying firms reduce transport-related climate impacts in their upstream supply chain, and (3) how to effectively collaborate with suppliers that are at different stages in their sustainability journey to achieve common climate targets.

Reductions in Scope 3 emissions are highly dependent on the ability of firms to manage complex interdependencies and foster collaborative relationships, both within and beyond organisational boundaries.

Effective emission reduction requires coordinated efforts across internal functions – such as purchasing, logistics, and production – and external actors, including product and transport suppliers and logistic service providers. It is important to understand the embeddedness of transport activities within supply networks and the need for tailored interaction patterns to address specific emission-reduction measures – such as the one identified in this study – that are more suitable for each relationship.

Changing Incoterms from DAP to FCA can significantly influence a buying firm's ability to reduce transport-related climate impacts in its upstream supply chain. Under DAP, the supplier retains control over transport arrangements, often prioritising costs and delivery date over environmental considerations. In contrast, FCA shifts the responsibility for transport to the buying firm, which allows greater control over decisions that impact on climate impacts. Thus, adopting FCA can help buying firms align their transport decisions with broader sustainability goals. However, this comes with certain risks and challenges that are worthy of further study

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Appendix

Appendix 1

Process Flow from Contract Signature to Invoicing

1. **Contractual Agreement Registration and Data Management**

Systems Involved: MDG (Master Data Governance) global portal and ERP.

Activities:

- Once a customer contract is signed, the legal and procurement departments register the contractual terms (including Incoterms, payment terms, currency, lead times, and pricing) in the MDG portal.
- Local procurement creates the ERP agreements to specify contractual terms, including lead times and pricing, aligned with the global portal entries.
- Changes to Incoterms are updated exclusively in the MDG portal and then reflected into the ERP, ensuring centralized control and consistency.

2. **Order Creation and Monitoring**

System Involved: ERP.

Activities:

- The sales department creates a sales order based on the signed contract, which triggers the procurement and logistics processes.
- Logistic Project Managers (LPM) monitor the order to ensure all necessary materials are acquired timely, coordinating with the procurement team.
- The procurement department generates purchase requisitions and purchase orders, referencing the contractual agreements. These are managed within the ERP, where lead times, pricing, and incoterms are specified per article.

3. **Material Acquisition and Delivery Preparation**

Systems Involved: MDG (Master Data Governance) global portal and ERP.

Activities:

- Procurement and logistics coordinate to ensure ordered parts are delivered on schedule, considering the specified Incoterms and lead times.
- Incoterms are adhered to, reflecting the responsibilities and transfer points for goods, as updated in the ERP system through the MDG portal.

- For international shipments, logistics plans are optimized to reduce transport emissions, incorporating route planning and transport modes.

4. **Goods Receipt and Quality Inspection**

System Involved: ERP.

Activities:
- Upon receipt at the site, goods are registered in the ERP as goods receipt (GR). This triggers the internal quality checks if necessary and updates inventory status.
- Returned parts are inserted into the process when required for refurbishment or service.

5. **Project Execution and Delivery**

System Involved: ERP.

Activities:
- The logistics team manages transport, adhering to Incoterms, and formats shipping documents (pick/pack/shipping).
- Shipment is executed, and the goods are delivered to the customer site or designated location, with monitoring to ensure timeliness.

6. **Billing and Invoicing**

System Involved: ERP.

Activities:
- After delivery, the invoicing process begins, based on project-specific parameters.
- The invoice reflects the contractual terms, delivery details, and agreed prices.

7. **Customer payments**

Systems Involved: MDG (Master Data Governance) global portal and ERP.

Activities:
Payment transactions are registered, completing the financial cycle.

- Feedback from the customer or project manager may trigger process adjustments, including updates to master data or contractual terms in the MDG system.

Additional Considerations:

1. The entire process is supported by the ERP and the MDG portal, with updates to master data reflecting changes in contractual or logistical parameters.
2. Sustainability efforts focus on optimizing routes and transport modes to minimize emissions throughout the logistics chain.