Supplier and Supply Chain Factors influencing Greenhouse Gas Emissions in the Automotive Industry

A case study at DAF Trucks N.V.

MSc Supply Chain Management

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Abstract

Purpose

This research investigates greenhouse gas emissions within the automotive industry's supply chain, focusing on emissions produced by suppliers and transport processes. This research aims to enhance the understanding of greenhouse gas emissions by measuring the emissions produced by suppliers of DAF Trucks, identifying drivers that influence greenhouse gas emissions, and providing a new framework.

Methodology

This study is based on a case study analysing sixteen metal component suppliers of DAF Trucks, selected via judgmental sampling. Qualitative and quantitative data were analysed during the study by distributing a survey, conducting supplementary interviews, and using internal archival data.

Findings

The findings identify several emissions drivers that impact supplier and/or supply chain emissions. Production processes are the predominant source of emissions within the automotive industry, while transportation emissions represent a relatively minor contribution to total emissions.

Value

This study contributes to the academic understanding of supply chain emissions by proposing a novel framework. This framework, presented in a 2x2 matrix, introduces an approach for evaluating sourcing decisions based on the intensity of supplier and supply chain emissions.

Preface

In the past few months, I conducted a study analysing supplier and supply chain factors influencing CO_2e emissions in the automotive industry. This thesis is part of my master's programme in Supply Chain Management at Tilburg University. Throughout the programme, I have had the opportunity to develop both my academic and personal skills through various courses and projects, learning to conduct research in an academic manner. This thesis marks the final step of my master's journey.

Beginning in late August 2024, I carried out my research at the DAF Trucks headquarters in Eindhoven, where I worked within the purchasing department of metal components. While collaborating with sixteen suppliers from around the world, valuable insights were gained into their practices and the challenges they encountered relating to more sustainable practices.

I would like to express my gratitude to DAF Trucks for providing me the opportunity to write my thesis at a global company that has fascinated me since my childhood. Having driven past the DAF Trucks site numerous times, I have always been interested in the company and its products. I am incredibly thankful to all my direct colleagues at DAF Trucks who supported me and assisted me throughout the research, and particularly Mr. Tarlan, my supervisor, for his guidance. Additionally, I would like to express my appreciation to the suppliers who played an essential role in this research by responding to the survey, sharing valuable insights during our discussions, and allowing me to visit their companies.

Lastly, I would like to thank Mr. Van de Kerkhof for his helpful feedback and support throughout the research process.

I look forward to applying the knowledge and skills I have gained during my master's program to my future career.

Luc Raijmakers
Eindhoven, January 2025

List of Abbreviations

AHP	Analytic Hierarchy Process
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CBAM	Carbon Border Adjustment Mechanism
CO	Carbon Monoxide
CO_2e	Carbon Dioxide Equivalent
CSR	Corporate Social Responsibility
CSRD	Corporate Sustainability Reporting Directive
DAF	Van Doorne’s Aanhangwagenfabriek/Automobielfabriek
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
ESG	Environmental, Social, and Governance
ETS	Emission Trading System
EU	European Union
GHG	Greenhouse Gas
GSCM	Green Supply Chain Management
HPDC	High Pressure Die Casting
IOA	Input-Output Analysis
LCA	Life Cycle Analysis
MCDM	Multi-Criteria Decision Making
NGO	Non-Governmental Organisation
OEM	Original Equipment Manufacturer
PG3	Product Group 3
SBTI	Science Based Targets Initiative
TBL	Triple Bottom Line
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

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1. Introduction

This chapter introduces the research by presenting the company's background. It is followed by an overview of the problem, theoretical contributions, managerial implications, problem statement, conceptual model, and the research questions that will guide the subsequent chapters.

1.1. Background

DAF Trucks N.V., founded on April 1, 1928, is a Dutch truck manufacturer headquartered in Eindhoven, the Netherlands. It operates as a subsidiary of PACCAR Inc., which also owns the American truck brands Kenworth and Peterbilt. In 2023, the PACCAR Inc. group reported total revenues of $33 billion. That same year, DAF Trucks produced over 69,800 trucks, achieving a market share of 15.6% in the heavy-duty market and securing market leadership in several countries, including Belgium (20.2%), Hungary (23.1%), the United Kingdom (28.8%), and the Netherlands (31.2%).

In recent years, DAF Trucks has made significant investments in sustainable transportation by launching several electric truck models including the DAF XB Electric, DAF XD Electric, and DAF XF Electric, which began series production in the fall of 2024 at its new electric assembly plant in Eindhoven. In addition to electrification, the company has also focused on improving the fuel efficiency of its diesel trucks. The 'New Generation DAF Trucks', introduced in 2021, achieved fuel savings of up to 10% compared to their predecessors. Additionally, its latest models, introduced in September 2024, offer an extra 3% reduction in fuel consumption compared to its older models. Collectively, these efforts have earned the company numerous awards, including the 2022 and 2023 Truck of the Year Awards (Truck of the Year, 2021a; Truck of the Year, 2022) and the 2022 Truck Innovation Award (Truck of the Year, 2021b).

These efforts are consistent with DAF Trucks' mission to establish itself as a global technology leader in providing sustainable transport solutions that drive the success of its customers. However, as the industry faces increasing pressure to meet environmental standards (Laosirihongthong et al., 2013), there is an urgent need for companies such as DAF Trucks to broaden their sustainability initiatives beyond vehicle performance and address the environmental impact across the entire supply chain.

1.2. Problem indication

While DAF Trucks has made significant progress in sustainable transportation, the environmental impact of the materials used throughout its supply chain has received limited attention. As global awareness of climate change grows (Alamillos & De Mariz, 2022; Lee, 2011), and stricter sustainability standards and regulations take shape (Murshed et al., 2021), it has become increasingly important for companies to address this impact. Therefore, DAF Trucks must evaluate the emissions associated with the materials and components within its supply chain.

Climate change has become a serious concern for policymakers, companies, and customers (Alamillos & De Mariz, 2022; Lee, 2011). This growing concern has led to adopting the triple bottom line (TBL), which measures a company's success across three interconnected dimensions: people, planet and profit (Elkington, 1998). The TBL encourages companies to commit to social responsibility, environmental stewardship, and economic viability (Amos & Uniamikogbo, 2016). Similarly, the Environmental, Social, and Governance (ESG) criteria provide a comprehensive framework for evaluating a company's sustainability practices. While both the TBL and ESG emphasise the importance of social, economic and environmental importance in business, ESG is often used by investors to assess risk and sustainability, while the TBL serves as a broader business philosophy (Alamillos & De Mariz, 2022; Jacobs, 2024). Understanding these principles highlights the importance of companies like DAF Trucks aligning their supply chain with broader sustainability goals.

In addition, the Corporate Social Responsibility (CSR) initiatives aim to integrate social and environmental considerations into business practices (Ioannou & Serafeim, 2014), while the newly implemented Corporate Sustainability Reporting Directive (CSRD) mandates sustainability reporting for large companies in the European Union since 2024 (Primec & Belak, 2022). Both the CSR and the CSRD highlight the growing importance of embedding sustainability into corporate strategies.

The automotive industry has embraced innovations such as biodiesel (Tashtoush et al., 2007), hydrogen (Pollet et al., 2019), and electric transportation (Günther et al., 2015). Similarly, DAF Trucks has made investments in electric and hydrogen transportation, as well as in optimising its manufacturing processes. However, limited research and time have been spent evaluating the environmental impact of DAF Trucks's supply chain, encompassing the sourcing of materials, and the processes undertaken by suppliers.

The metal industry supplies a substantial portion of materials required for truck manufacturing and is a major contributor to Greenhouse Gas Emissions such as CO_2, (International Energy Agency, 2017; Takayabu et al., 2019; Worrell et al., 2008). The industry faces several challenges, such as the depletion of non-renewable natural resources (Moors et al., 2004). Given that DAF Trucks sources metals globally for its operations and seeks to align with EU regulation, ESG objectives, and the company's sustainability goals, it is critical to understand and mitigate the environmental impact of these materials.

Meanwhile, literature emphasises the importance of effective supply chains for gaining competitive advantage (Hult et al., 2007) and adopting sustainable practices (Seuring & Müller, 2008). Environmental challenges often extend beyond individual companies, affecting entire supply chains rather than being confined to a single entity (Seuring et al., 2008). This interconnected nature of supply chains highlights the need to analyse emissions across the entire supply chain.

Current literature extensively discusses the importance of sustainable practices within the supply chain (Hong et al., 2017; Morali & Searcy, 2012; Okoye et al., 2024) and highlights the positive relationship between green supply chain practices and operational performance (Azevedo et al., 2011). However, it provides limited insights into the factors influencing green practices and CO_2 emissions. Terms such as 'minimise waste' and 'improve efficiency' (Andalib et al., 2022; Azevedo et al., 2011) are commonly referenced, but they often overlook the specific supplier and supply chain elements that directly impact sustainable practices. Identifying and understanding these factors can be essential for reducing the environmental impact of the automotive supply chain. This research focuses on identifying and analysing these factors within the supply chain and at suppliers.

1.3. Theoretical contributions

Literature on strategic supply chain management emphasises the importance of sustainability and operational efficiency in improving environmental and economic outcomes (Pagell & Wu, 2009; Seuring, 2001; Seuring & Müller, 2008). Various methods suggest several methods for improving supplier sustainability, such as supplier assessment and enhanced collaboration (Gimenez & Tachizawa, 2012). Global supply chain literature also highlights practices such as supplier evaluations, collaboration, and multi-stakeholder initiatives (Caniato et al., 2013; Formentini & Taticchi, 2016; Gualandris et al., 2015; Koberg & Longoni, 2018; Turker & Altuntas, 2014).

While existing knowledge predominantly focuses on scope 1 emissions (direct emissions at the firm's facilities) (Shrimali, 2021), more recent attention has turned to scope 2 and scope 3 emissions, which often constitute a more significant portion of a supply chain's total emission (Hertwich & Wood, 2018). Scope 2 emissions come from purchased electricity (Makadok et al., 2018), and scope 3 emissions cover indirect emissions from upstream and downstream processes (US EPA, 2024). Although some studies address firm-level factors affecting GHG emissions within purchasing (Eggert & Hartmann, 2021), scope 3 emissions remain not adequately explored.

Despite the valuable contributions made by these studies, there exists a notable gap in the identification of specific factors that influence emissions at the supplier level, and scope 3 emissions remain not adequately explored. Furthermore, the current literature lacks a comprehensive framework that delineates the relationship between supplier and supply chain emissions and strategies to mitigate emissions across the supply chain.

This study aims to bridge existing gaps in the literature by introducing the concepts of 'supplier factors' and 'supply chain factors'. These variables are examined in the context of their impact on GHG emissions, providing new perspectives on how supplier and supply chain factors contribute to GHG emissions. According to the study by Makadok et al. (2018), several levers can be adjusted to make theoretical contributions. This research aims to expand our theoretical understanding by introducing and defining these variables, investigating their impact, and exploring the mechanisms through which these factors influence GHG emissions.

1.4. Managerial implications

This research aims to provide a transparent and detailed overview of GHG emissions within the automotive supply chain. Companies can gain clearer visibility into their environmental impact by identifying specific supplier and supply chain factors contributing to GHG emissions. This research aims to enable managers to make more informed decisions about their sustainability goals and the selection of suppliers. Moreover, the study aims to outline how managers can use the findings from this research to optimise their supply chain. Companies can engage more with suppliers to reduce emissions by focusing on the key findings of this research. Additionally, reducing emissions in the supply chain can enhance brand image and give companies a more competitive advantage.

For policymakers, the insights from this research can provide evidence on how specific supplier and supply chain factors influence emissions. Policymakers can use the study's findings to design regulations that encourage more sustainable supply chain management. This study contributes to broader environmental sustainability goals by providing companies with tools to reduce their carbon footprint and optimise their supply chains.

1.5. Problem statement

The problem statement for this research is: "What supplier and supply chain factors within the automotive and metal supply chain are the main drivers of CO_2e emissions?"

1.6. Conceptual model

Figure one provides the conceptual model developed from the previous paragraphs. The conceptual model represents the relationship between supplier and supply chain factors, and CO_2e emissions.

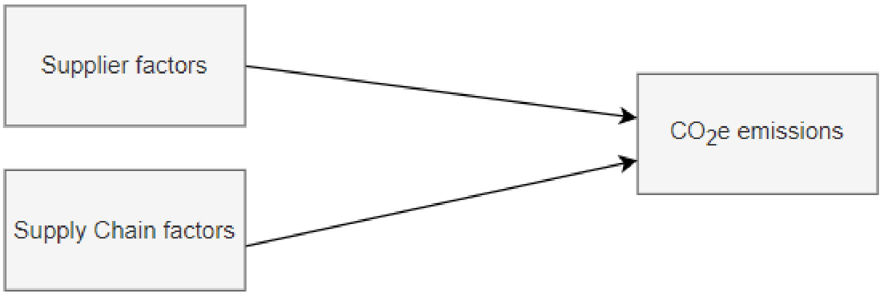


Figure 1: Conceptual model.

1.7. Research questions

The research questions listed below are derived from the problem statement and conceptual model, and they aim to provide answers to the problem statement.

Theoretical questions:

- What are greenhouse gas emissions, and how are these emissions measured?
- What are the primary sources of greenhouse gas emissions within the automotive industry and its supply chain?
- What are the factors related to suppliers and supply chains that influence greenhouse gas emissions?

Empirical questions:

- What are the primary sources of GHG emissions at suppliers within the automotive industry?
- What are the primary sources of GHG emissions in the automotive industry's supply chain?
- How do supplier emissions compare to supply chain emissions in terms of their contribution to overall GHG emissions within the automotive industry?
- What are the key factors influencing GHG emissions at suppliers within the automotive industry?
- What are the key factors influencing GHG emissions in the automotive industry's supply chain?

2. Literature review

This chapter provides an overview of existing literature on greenhouse gas emissions. This chapter is structured as follows: The first section presents an overview of greenhouse gas emissions, corresponding to the first theoretical question. The subsequent section discusses the primary sources of emissions within the automotive industry, which corresponds to the second research question. The last two sections examine the factors related to suppliers and the supply chain that influence greenhouse gas emissions, addressing the last theoretical question.

2.1. Greenhouse Gas emissions

2.1.1. Defining Greenhouse Gas emissions

Greenhouse gases (GHGs) play a crucial role as the Earth's natural temperature regulators, essential for maintaining the balance necessary to support life on our planet (Knutti & Hegerl, 2008). These gases trap heat, warming the Earth and making it habitable (EPA, 2024; NASA, n.d.). However, since the Industrial Revolution, human activities, particularly the burning of fossil fuels, have disrupted this balance (Ghannoum et al., 2010; Stocker et al., 2013). The increased emission of GHGs into the atmosphere has led to global warming and climate change (Stocker et al., 2013). The effects of climate change are now unmistakably observed worldwide, manifested as extreme warmth, heavy rainfall, floods, and droughts (Ghannoum et al., 2010; Lamb et al., 2021; Solomon et al., 2008).

The urgency of addressing climate change has led to the establishment of several international conventions and agreements, such as the United Nations Convention on Climate Change (United Nations, 1992), the Kyoto Protocol (Babiker et al., 2000), the Paris Agreement, adopted by 195 countries in 2015 (Paris Agreement, 2015; Seo, 2017), and the European Green Deal (Pietzcker et al., 2021). These agreements outline ambitious goals for reducing GHG emissions.

The Intergovernmental Panel on Climate Change (IPCC), identified Carbon Dioxide (CO_2), Methane (NH_4), Nitrous Oxide (N_2O), and Halocarbons as the primary gases driving climate change (Calvin et al., 2023), with CO_2 representing the largest share at 81.3% of total emissions (De Araujo et al., 2007; EPA, n.d.). It is important to note that different GHGs have varying lifespans in the atmosphere. The Global Warming

Potential (GWP) is a measure used to compare the relative impact of different greenhouse gases on global warming over a specified time period (Brander, 2012). CO_2 serves as the baseline with a GWP value of 1. CH_4 has a GWP of 25; N_2O has a GWP of 98; and Halocarbons vary between 124 and 14,800. The Carbon Dioxide equivalent (CO_2e) is a commonly used metric for describing different GHGs in an unified CO_2 unit. The Carbon Dioxide equivalent can be calculated by multiplying the GHG by the GWP (Brander, 2012). CO_2e will be the standard measure in this research.

Current literature discusses the importance of managing GHGs within companies for several reasons. Firstly, companies need to comply with (future) regulatory requirements and actively work on reducing their emissions (*CO2-heffing Voor Industrie*, 2024). Secondly, managing emissions has financial implications, as it can lead to cost savings, efficiency improvements, and avoidance of future fines (*CO2-heffing Voor Industrie*, 2024; Iftikhar et al., 2016). Thirdly, emissions can affect a company's reputation, as being perceived as environmentally responsible is increasingly important for stakeholders and consumers (Ganescu & Dindire, 2014). Furthermore, effective GHG management can create a competitive advantage (Olatunji et al., 2019). Some companies to actively address or meet specific GHG reduction targets. The reasons outlined above underscore the importance of acknowledging and managing GHG emissions for a company's long-term viability and sustainable growth.

Building a more sustainable supply chain presents several challenges. One key obstacle is a lack of transparency within the supply chain (Zhao et al., 2012). Additionally, identifying the factors that influence emissions is another challenge (Ahi et al., 2015). Various methods can be employed to assess the environmental impact of materials. One widely utilised method is the Life-Cycle Analysis (LCA), which evaluates the materials used, energy consumption, and waste disposal throughout the product life cycle (Abdallah et al., 2012; Pishvaee & Razmi, 2011). Another commonly used method is the Analytic Hierarchy Process (AHP), which helps organise and analyse complex multi-objective decisions (Saaty, 2009). Other methods include Multi-Criteria Decision Making (MCDM), and Input-Output Analysis (IOA) (Ahi et al., 2015).

2.1.2. Regulations on Greenhouse Gas emissions

A proper method or guideline needs to be adopted for organisations to gain a comprehensive understanding of their GHG emissions. The World Resources Institute (WRI), the World Business Council on Sustainable Development (WBCSD), NGOs, and governments developed the Greenhouse Gas Protocol (GHG Protocol) (Ranganathan et al., n.d.). Today, the GHG Protocol is widely recognised as a leading guideline for GHG Accounting (Hickmann, 2017).

GHG Protocol

In order to identify direct and indirect emissions associated with a company, the GHG Protocol defined three categories: scope 1, scope 2, and scope 3 (Hickmann, 2017). Scope 1 emissions include direct GHG emissions that occur from sources that an organisation owns. This includes activities such as electricity generation, internal transportation, and fugitive emissions (Ranganathan et al., n.d.). Scope 2 emissions encompass all emissions resulting from the generation of purchased electricity and heat (Ranganathan et al., n.d.). Scope 3 emissions include all other indirect emissions from sources not owned by the company (Hickmann, 2017; Ranganathan et al., n.d.). While scope 1 and scope 2 emissions are mandatory to assess within the GHG Protocol, scope 3 emissions are optional (Ranganathan et al., n.d.).

Several studies have underscored the significance of scope 3 emissions. Matthews et al. (2008) found that on average only 26% of GHG emissions are captured under scope 1 and scope 2 emissions, based on a study conducted of 491 industries in the US. Similarly, the WBCSD and the WRI (Ranganathan et al., n.d.) reported that scope 3 emissions account for at least 80% of GHG emissions (Hickmann, 2017). In addition, Hertwich and Wood (2019) emphasised the importance of scope 3 emissions, showing their substantial share in various industries, with the energy industry contributing 20% and the manufacturing industry 80% in scope 3 emissions. Furthermore, researchers have documented an upward trend in scope 3 emissions over time. Between 1995 and 2015, scope 2 and scope 3 emissions increased by 83%, compared to a modest 47% in scope 1 emissions (Hertwich & Wood, 2018). These findings highlight the necessity of measuring scope 3 emissions to comprehensive understand their impact.

The GHG Protocol distinguishes between scope 3 upstream and scope 3 downstream emissions. Upstream emissions occur before a company's direct operations, whereas downstream emissions occur after the company's operations. Within upstream and downstream emissions several categories have been identified, as seen in the figure below. Despite the significance of analysing scope 3 emissions, current literature has not offered extensive research on this topic (Lehmann et al., 2017; Mahapatra et al., 2021; Mahdiloo et al., 2015). While scope 3 emissions have not been researched in sufficient detail, specific downstream categories, particularly the "Use of sold products", have received more attention (Wang et al., 2024). However, a gap remains in the literature concerning measuring upstream scope 3 emissions. This literature review will examine categories 1 and 4 of scope 3 emissions, as these categories are under-researched and of significant importance within the automotive and metal industries.

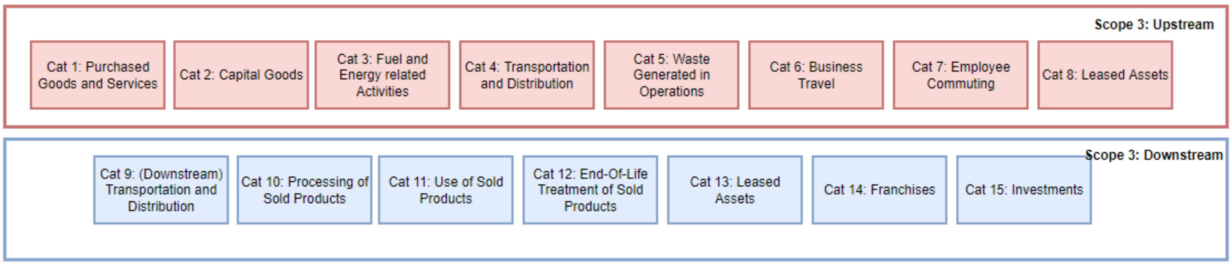


Figure 2: Scope 3 upstream and downstream categories.

2.1.3. Purchased Goods and Services & Transportation and Distribution

Scope 3 cat 1: Purchased goods and services.

Scope 3 cat. 1 emissions refer to emissions associated with the entire value chain of an organisation's purchased goods and services, including the emissions resulting from the mining and production of these goods and services at other companies (GHG Protocol, 2022a). However, emissions arising from the transportation of these goods are included in scope 3 category 4. A common distinction is made between production-related products (such as metal, plastic, and parts) and non-production-related products (such as office furniture and office supplies) (GHG Protocol, 2022a).

Several methods can be used to calculate the emissions. The literature discusses the supplier-specific method, which requires the reporting company to gather cradle-to-gate GHG inventory data from its suppliers for each product or service. Another method is the hybrid method, which combines supplier-specific activity data with secondary data. In this method, the reporting company collects scope 1 and scope 2 emissions directly from suppliers. When supplier-specific data is unavailable, upstream emissions are calculated using secondary data. A third method, the average data method, estimates emissions for goods and services by collecting data on the mass or other relevant units of the products and multiplying this with relevant secondary emission factors. Lastly, the spend-based method, calculates emissions by collecting data on the economic value of the purchased goods and services and multiplying this by relevant secondary emission factors (GHG Protocol, 2022a).

Scope 3 cat 4: Transportation and distribution

Scope 3 category 4 emissions encompass emissions from the transportation and distribution of products between a company's tier 1 suppliers and its operations in vehicles not owned by the reporting company. This category includes various modes of transportation, such as, air, road, rail, and sea.

To clarify, emissions occurring between a tier 2 and a tier 1 supplier are captured under scope 3 category 1, and the reporting company's scope 3 category 4 emissions are the third-party transportation company's scope 1 emissions (GHG Protocol, 2022b).

2.2. Industries

Several industries are major contributors to GHG emissions, with the automotive sector being one of the significant emitters (ESA, n.d.; Ibrahim et al., 2021). Within the automotive industry, four key sources of emissions can be identified throughout the product's lifecycle: (1) Upstream supply chain and production emissions, (2) tailpipe emissions during the use phase, (3) emissions from fuel production, and (4) end-of-life emissions after lifetime (Smeets, 2022). Upstream supply chain and production emissions (scope 3 upstream emissions) account for a substantial percentage of the total CO_2 emissions during the lifecycle of a product in the manufacturing industry (Hertwich & Wood, 2018). One of the most critical material components within the manufacturing of a truck is steel. Steel accounts for more than 67% of the total weight of a truck (DAF Trucks N.V., 2023). Reducing scope 3 upstream emissions holds significant potential for mitigating the CO_2 emissions with truck manufacturing.

While the automotive industry began measuring its their scope 1 and scope 2 emissions a few years ago, scope 3 emissions are not widely tracked. This conclusion is drawn from an analysis of several major European truck manufacturers, as well as significant manufacturers from China, Japan, India, and the USA (see Appendix 1). According to this analysis, only 20% of truck manufacturers within the automotive industry track their upstream scope 3 emissions, whereas all measure scope 1 and scope 2 emissions.

The metal industry is of unquestionable importance to the automotive industry, as the automotive industry extensively relies on metal components. The steel industry is one of the most significant sources of CO_2 emissions, contributing to 9% of total emissions globally (Takayabu et al., 2019; World Steel in figures, 2024). This impact is caused by the steelmaking production process, which requires high temperatures and energy-intensive processes to transform raw materials into steel. Within the industry primarily two processes for steel production are used: (1) Blast Furnace – Basic Oxygen Furnace (BF-BOF), and (4) Electric Arc Furnace (EAF) (World Steel in figures, 2024; Xue et al., 2024). BOF currently accounts for approximately 72% of total steel production, and EAF for 28% (Xue et al., 2024).

BF-BOF

The BF-BOF process is most commonly used within the industry. In this method, iron ore (Fe_2CO_3) is converted to iron in a blast furnace and then refined in a basic oxygen furnace to produce steel. Carbon (from coke) is used to strip oxygen atoms from iron oxide using a chemical reaction, producing iron and CO_2. This makes the BF-BOF process a high-CO_2 emitting method. Carbon not only serves as an energy source, but also as a chemical component to separate iron from its oxide form.

Reaction:
Coke combustion: $C + O_2 \rightarrow CO_2$ (coke is combusted in presence of oxygen).
Carbon monoxide formation: $CO_2 + C \rightarrow 2CO$ (CO_2 formed react with additional coal).
Reduction of iron ore: $Fe_2CO_3 + 3CO \rightarrow 2Fe + 3CO_2$ (reaction in the blast furnace of iron ore, making liquid iron and CO_2).

According to the World Steel database, on average, approximately 2.33 tonnes of CO_2 are emitted for each tonne of crude steel produced (World Steel in figures, 2024). Furthermore, the process requires a significant amount of energy, with an average demand of 20.99 GJ per tonne of steel on average (World Steel in figures, 2024).

EAF

The EAF process is a less widely used approach compared to the BF-BOF process. It significantly reduces direct CO_2 emissions by primarily utilising recycled scrap metal. This method eliminates the need for iron ore reduction, as it melts scrap steel using electricity. On average, approximately 0.68 tonnes of CO_2 per tonne of steel is emitted, and 10.07 GJ of energy is used. When using Direct Reduced Iron (DRI) instead of iron, the EAF process requires natural gas as a reducing agent, resulting in on average 1.37 tonnes of CO_2 per tonne of steel and 22.58 GJ of energy (World Steel Association, 2023).

Within the automotive industry, several key components are made with flat steel, forgings and casting processes. Flat steel is a category of steel products characterized by their flat, thin shapes. Forging is a manufacturing process that involves shaping metal using compressive forces. Casting, on the other hand, involves pouring liquid material into a mould and allowing it to solidify.

An analysis of the publicly available sustainability reports of various metal manufacturers and companies utilising metal reveals that not all companies currently publish such reports (see Appendix 2). Among those that do, scope 1 and scope 2 are measured, while only a small subset of them partially measure scope 3 emissions, aligning with earlier findings in this chapter.

2.3. Factors influencing GHG emissions

This section examines various factors influencing scope 3 emissions, as identified by the literature. Although management activities to reduce carbon emissions are widely discussed (Lee, 2011; Wiedmann & Minx, 2008), more information about scope 3 emissions and factors influencing these scope 3 emissions have to be analysed, as also emphasised by Matthews (2008). Knowledge of scope 3 emissions sources can inform and help in purchasing, investing, claiming carbon credits, and policymaking

(Downie & Stubbs, 2012). Assessments of scope 3 GHGs also help organisations identify best mitigation opportunities, regardless of a firm's internal boundaries (Huang et al., 2009b). Literature focused extensively on understanding carbon footprints (Wiedmann & Minx, 2008), identifying key stakeholders responsible for emissions in a supply chain (Andrew & Forgie, 2008), examining double-counting in assessing emissions (Murray et al., 2008), and debating what sources should be included when measuring emissions (Wiedmann & Minx, 2008). Huang et al. (2009a) concluded that provisioning sector specific scope 3 guidelines would significantly enhance accuracy. However, a clear understanding of these guidelines, or the factors to be considered when establishing them, remains unclear.

Transport and logistics enable the trade of physical products between companies and countries. Logistics is commonly defined as 'that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services and related information from point of origin to point of consumption on order to meet customers' requirements' (Lambert et al., 1998a). Another simpler definition used: 'The movement and transmittal of goods, services and information' (Lummus et al., 2001). The physical part of logistics is concerned with the flow of products. Within a supply chain, it encompasses the transportation between suppliers and manufacturers. Emissions within transportation can vary substantially based on some key factors (Barberio Mariano et al., 2017). One key source influencing GHG emissions is the distance between the supplier and manufacturer (Heinen et al., 2019). Logically, greater distances between the manufacturer and supplier result in higher CO_2 emissions. The transport type used during transportation is another important factor to consider when calculating CO_2 emissions (Barberio Mariano et al., 2017; Ragon et al., 2021). Transport is typically conducted via air, rail, road, or sea. When selecting a mode of transport, fuel source and fuel economy are important factors to take into considerations (Ragon et al., 2021). For example, while trucks traditionally use diesel fuels, electric trucks, though still relatively uncommon, are gradually being introduced. In addition to diesel, trucks may also use gasoline, CNG, LPG, LNG, or biodiesel ("Guidelines For Measuring And Managing CO_2 Emission From Freight Transport Operations", 2011). Load optimisation, whether partial or full loads, also plays a role in emissions and fuel economy because it directly affects the efficiency of transportation processes (Wild, 2021). Collectively, these factors impact GHG emissions during transport (Ranganathan et al., n.d.).

As outlined in the previous chapter, the production method plays a critical role in determining the emissions during manufacturing (Rathi & Jakhade, 2014; Wangchuk et al., 2021; World Steel in figures, 2024; World Steel Association, 2023; Wangchuk et al., 2021). This includes processes such as casting and forging. However, it is not the casting or forging processes themselves that result in high emissions, instead it is the associated heating, heat treatment, and machining processes before and after production that contribute significantly. Another important factor of emissions is the type of material used, as discussed earlier in this chapter. According to current literature, the environmental impact of steel production is higher when using a Blast Furnace compared to an Electric Arc Furnace (Li et al., 2017) and when using primary material instead of recycled material (Gorman et al., 2022). Additionally, the type of energy used during the manufacturing process also plays an important role in the total emissions (GHG Protocol, 2022a; GHG Protocol, 2022b; Menghi et al., 2019)

Other management-related activities that influence CO_2 emissions are linked to (energy) innovations adopted by companies. Innovation is commonly defined as: ‘the creation of new knowledge and ideas to facilitate new business outcomes aimed at improving business processes’ (Du Plessis, 2007). Another factor discussed in the literature is supplier engagement (Butt et al., 2024; Wohlgezogen et al., 2020). Achieving sustainability and effectively measuring scope emissions requires the active participation of all partners, coupled with a commitment to continuous improvement (Butt et al., 2024; Wohlgezogen et al., 2020). Addressing and visualising emissions requires collaboration with suppliers (Butt et al., 2024).

Although the factors mentioned above are discussed in existing literature, there is a notable gap in the research regarding a comprehensive and consolidated list of all these factors influencing emissions. Current studies do not provide a clear, unified framework that identifies and categorises the various factors affecting emissions (Lehmann et al., 2017; Mahapatra et al., 2021).

2.3.1. Supplier and Supply Chain

The current manufacturing landscape is defined by intense competition and demanding customers (Rathi & Jakhade, 2014). In the past, particularly in the 1930s, companies aimed to handle almost every aspect of production and sales internally, exemplified by Ford's comprehensive integration of stages. However, in recent times, outsourcing has become prevalent, with organizations relying on external partners for various activities (Iqbal & Dad, 2013). This shift has resulted in a transition from company-centric to supply chain-centric competition, where the focus is on the performance and collaboration of entire supply chains rather than individual companies (LeMay et al., 2017), also referred to as network competition.

When considering the previously discussed variables, it is important to differentiate between supply chain and supplier factors. To establish this differentiation, it is necessary to define what a supply chain means. Although there is no consensus on the precise definition of a supply chain among academic papers (LeMay et al., 2017), the most commonly used definition is the alignment of firms involved in bringing products or services to the market (Lambert, et al., 1998b). This includes manufacturers, suppliers, transporters, warehouses, wholesalers, retailers, and even customers. Understanding this definition enables a more thorough analysis and identification of the factors that impact the supply chain as a whole, as well as the individual suppliers within it.

In addition to analysing the supply chain, it is crucial to delve into the analysis of suppliers. While companies may understand their direct impact well, they often lack visibility into their suppliers' suppliers. First-tier suppliers refer to the direct suppliers of a company. On the other hand, second-tier or lower-tier suppliers are the ones that supply a company's direct suppliers. Even though these suppliers may be further down the supply chain, they still influence scope 3 emissions and need to be taken into account when calculating emissions. By considering the emissions associated with these suppliers, companies can gain a more comprehensive understanding of the environmental impact of their supply chain and identify opportunities for emissions reduction throughout the entire chain.

Supplier factors in this study apply to internal attributes and qualities specific to individual suppliers. In contrast, supply chain factors encompass the variables and dynamics between companies within the supply chain. This understanding allows for differentiation between the characteristics inherent to each supplier and those that emerge from the interactions and relationships within the supply chain.

2.4. Framework

The figure below provides a framework consisting of an overview of the topics discussed above.

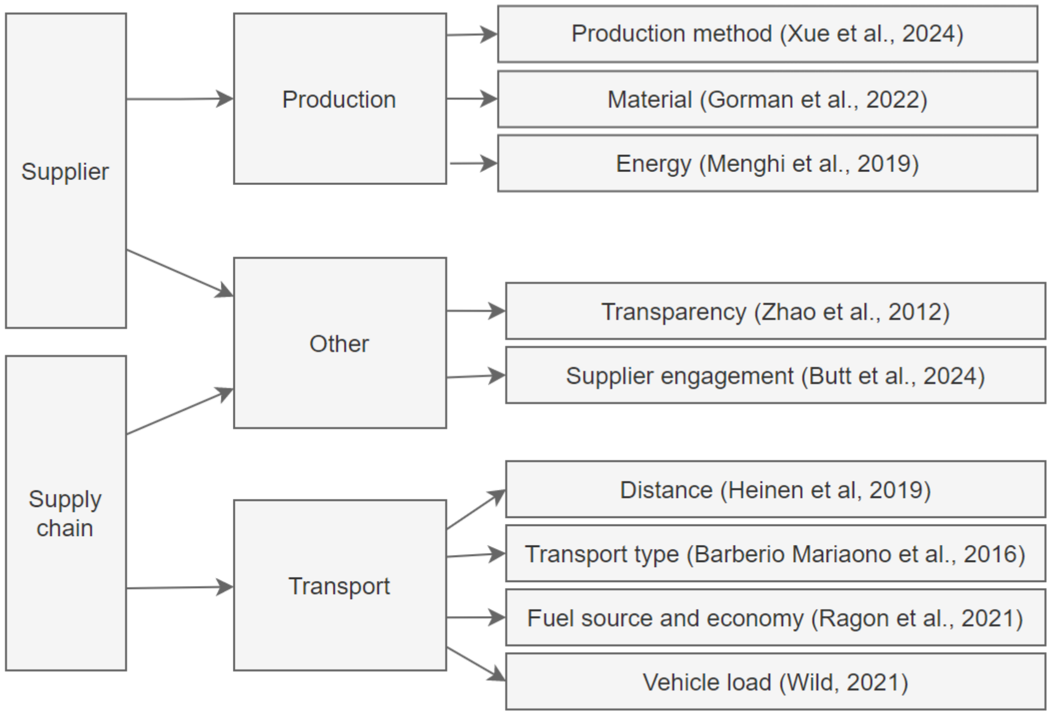


Figure 3: Supplier and supply chain factors driving emissions.

Research gap

Despite the importance of scope 3 emissions within the automotive and metal industry, the current literature lacks extensive research on upstream emissions (Lehmann et al., 2017; Mahapatra et al., 2021; Mahdiloo et al., 2015). Although various factors influencing emissions have been discussed in different contexts, no comprehensive list consolidates these elements. As a result, a gap exists in research focused on identifying and analysing the specific factors that influence scope 3 emissions

(Lehmann et al., 2017; Mahapatra et al., 2021) and strategies to decrease these emissions.

3. Methodology

This research was conducted within Purchase Group 3 (PG3) at DAF Trucks in Eindhoven. This group is responsible for procuring metal components from a network of approximately eighty suppliers globally.

3.1. Research Nature

This study is positioned within an intermediate stage of theoretical development concerning scope 3 emissions. According to the research conducted by Edmundson and McManus (2007), a hybrid approach incorporating both quantitative and qualitative data is most effective when the theory is in an intermediate state. Therefore, this study adopts a hybrid inductive research approach, combining elements of both qualitative and quantitative research methods. The unit of analysis is on the individual-supplier level. By focusing on several individual suppliers, this study aims to better understand the drivers of scope 3 emissions. Given the limited timeframe for this research and the focus on understanding the current drivers and emissions of suppliers, a cross-sectional research design is employed rather than a longitudinal study.

3.2. Research Strategy

The research strategy adopted for this study is a case study approach. Case studies are particularly effective in examining the dynamics within a single setting, generating theory, and often involve integrating multiple data collection methods (Eisenhardt, 1989). This research also adopts a mixed-methods strategy that integrates qualitative and quantitative methods within a single study, and follows the process discussed by Eisenhardt (1989).

A survey was distributed to sixteen first-tier suppliers of DAF Trucks. Within this survey, a combination of qualitative and quantitative data on the suppliers' emissions was collected. Following the survey, interviews were conducted with all sixteen suppliers. During these interviews the information given in the survey was validated and additional questions were asked to explore their responses in more detail. Additionally, an in-depth analysis was carried out at two selected suppliers to gain a more comprehensive understanding of their sustainability challenges and strategies. In addition to the survey and interviews, secondary archival data was utilised to analyse the emissions associated with transportation.

3.3. Data collection

The Pareto Principle, also known as the 80/20 rule was employed to collect and select suppliers for the research done in this paper (Powell & Sammut-Bonnici, 2014). This principle, observed by the economist V. Pareto, illustrates the correlation between a small percentage of causes leading to a large percentage of effects, typically expressed as K ≈ 20/80.

In this study, a purposive sampling strategy, also called judgmental sampling (Sharma, 2017), was utilised in conjunction with the Pareto Principle. By focusing on the expenditures of all suppliers within the purchasing department for metal components, the applicability of the Pareto Principle became evident. Approximately 20% of the suppliers account for around 80% of the total expenditures.

This principle guided the selection of first-tier suppliers involved in the most critical production processes for metal components: flat steel, stampings, forgings, aluminium casting, and iron casting. The table below displays the total turnover percentage of the selected suppliers at DAF Trucks, categorized by production method.

Production method	**Number of selected suppliers**	**Turnover percentage**
Aluminium Casting	4	79.8%
Iron Casting	2	84.4%
Flat Steel Mill	3	78.8%
Forgings	4	80.5%
Stampings	3	74.0%

Table 2: Turnover percentage by production method for selected suppliers.

Several reasons justify the choice of this sampling technique. In the first place, selecting a small percentage of suppliers allowed the research to be conducted effectively within the limited timeframe available for this study. While including a more significant number of suppliers could enhance the reliability and validity of the findings, focusing on a manageable group was more practical given the time constraints. In addition, this approach ensured that the suppliers representing the largest share of expenditure, and consequently, the highest CO_2 emissions, were included in the analysis. Lastly, a comprehensive overview of the metal department can still be achieved by differentiating between various production methods.

As part of the data collection phase, surveys were distributed to all sixteen first-tier suppliers identified in the previous section. Two distinct questionnaires were sent to the suppliers, one for EU suppliers and another for non-EU suppliers.

EU Suppliers

The first questionnaire, designed for EU suppliers, contained twenty questions. It focused on various aspects of sustainability, such as their scope 1, 2, and 3 emissions, challenges they encountered when measuring emissions, and future investments to reduce emissions. The complete questionnaire can be found in Appendix 3.

Non-EU Suppliers

The second questionnaire, which was directed to non-EU suppliers and contained a total of 33 questions, was an extended version of the first questionnaire. This version included additional questions on transportation, which were necessary to understand DAF Trucks' scope 3, cat. 4 emissions. The complete questionnaire is available in Appendix 4. The first 20 questions were identical to both EU and non-EU suppliers, ensuring consistency in core data collection.

Both questionnaires were conducted via Qualtrics, an online survey tool provided by Tilburg University, which easily enables structured data collection. A link to the questionnaire was sent to all the Account Managers of the selected suppliers. The mail emphasised that the questionnaire should ideally be completed by the Sustainability Manager or another relevant individual or team within the company that focuses on sustainability. This approach was intended to enhance the quality of the research. To facilitate honest and valid responses, the questionnaire explicitly stated that if any question was unknown or not applicable, the suppliers could opt to leave it unanswered. Additionally, participants were assured that their responses would be kept confidential and used solely for this research and internally within DAF Trucks. This assurance aimed to decrease any confidentiality concerns and encourage the suppliers to answer truthfully.

Interviews

All sixteen suppliers replied to the questionnaire within the discussed timeframe. Following the survey, interviews with all suppliers were planned and conducted to validate the information provided in the questionnaire. The interviews were semi-structured (to obtain detailed responses and provide flexibility to the interviewer) and were conducted via Microsoft Teams, with at least the Account Manager and the Sustainability/ESG manager present from the supplier's side. Additional questions were asked during the interviews to further explore and clarify responses, addressing any ambiguities or discrepancies identified during the data analysis phase. The semi-structured interview guide is provided in Appendix 5.

Company visits

Company visits were conducted at two suppliers to gain a deeper understanding of their production processes, and sources of emissions. The visits took place at a flat steel mill in the Netherlands and an iron casting supplier in Germany.

Appendix 6 summarises all relevant information regarding the distribution of the questionnaires, the dates of replies, the follow-up interviews, and the participants involved in those interviews. In addition to the questionnaires completed by the suppliers, an Excel document was used to get quantitative information on all the suppliers' shipments to DAF Trucks (Excel document: 'Transporeon orders 2024 YTD (Q3)'). This document included all the shipments per supplier, the starting address of each shipment, the end address, the type of each shipment, the logistics provider used, and the weight of the shipment.

3.4. Data analysis

This section outlines the data analysis methods used in this research, focusing on the primary quantitative and qualitative data and internal secondary archival data.

3.4.1. Production data analysis

Production data was obtained through surveys, interviews, and two company visits. The analysis had a multifaceted aim.

1. Quantify emissions per supplier and identify the primary sources of emissions.
2. Understand supplier-level sustainability initiatives and challenges.

3. Validate survey responses through the interviews.

Qualitative analysis

The qualitative data from the interviews were transcribed verbatim to ensure accuracy. The grounded theory approach, developed by Glaser and Strauss (1968), was employed to generate theory directly from data rather than starting with a predefined hypothesis. As Miles and Huberman (1994) described, coding was used to systematically organise and analyse the data. When coding, recurring themes were identified, such as ‘governmental investments’ and ‘public pressure’, and connections were established and grouped. The coding scheme in Appendix 7 presents more detailed information.

Quantitative analysis

Quantitative data from the survey provided insights into the emissions per supplier and their production process. The analysis focused on calculating average emissions per production process and allocating these emissions between scope 1, scope 2, and scope 3.

3.4.2. Transport data analysis

Archival data

The archival data for this research was obtained from an internal database at DAF Trucks, which contained all transport orders recorded between January 1, 2024, and October 31, 2024. This dataset comprised a total of 68,022 rows, each representing a unique transport order. Given the focus on sixteen specific suppliers, a systematic cleaning process was employed.

Data cleaning

The first step of the cleaning process involved including only those suppliers relevant to the study. Subsequently, the dataset was filtered based on shipping addresses, focusing exclusively on transport orders to DAF Trucks facilities in Eindhoven or Westerlo. To further refine the dataset, criteria were applied to exclude any rows with shipment weights exceeding 40 tons, as shipments above this weight were deemed inaccurate. After cleaning the data, distances between the shipping addresses were calculated to facilitate an assessment of transport emissions based on distance and transport weight. The final dataset consisted of 4,852 rows. A detailed explanation of the cleaning phase is presented in Appendix 8.

Survey data

To address missing data in the archival data, additional transport-related data were gathered through the survey targeting the six non-EU suppliers. The data gathered via the survey included transport distances, modes of transport used, and the frequency of shipments. Upon receiving the survey responses, the data from the non-EU suppliers was collected and integrated with the archival document. This integration involved standardising the data formats to ensure that all variables were in the same form.

3.5. Reliability and Validity

Reliability

Reliability refers to the consistency and stability of a measurement (Bannigan & Watson, 2009). In academic research, high reliability indicates that if the same study were conducted multiple times under similar conditions, it would have similar results. This consistency is crucial because it assures researchers that the findings are reflective of the true nature of the phenomenon being studied rather than being influenced by random errors or biases. To enhance the reliability of this research, a pilot test was conducted with several colleagues before the questionnaire was sent to suppliers. This process allowed for identifying and refining ambiguous and vague questions, ensuring clarity and comprehension to the respondents. Secondly, the data collection methods were standardised as much as possible across suppliers to ensure internal consistency and repeatability.

Validity

Validity refers to the extent to which the research measures what it intended to measure (Bannigan & Watson, 2009). This paragraph addresses both internal and external validity. Internal validity examines whether a study accurately answers its research questions without bias (Yin, 2013). Several biases were identified in this research, including response bias, selection bias, and interviewer bias. Response bias, where suppliers may provide socially desirable answers regarding their environmental practices and driven by social desirability, was a key concern. To mitigate this bias, the anonymity of responses was assured, reducing pressure on suppliers. Moreover, clear definitions of key terms were provided in the questionnaire to reduce ambiguity and ensure consistent understanding across all respondents. Additionally, supplier meetings were conducted to validate the questionnaire response, allowing for clarifications and deeper insights.

Data triangulation was employed to verify supplier responses and to compare findings with existing literature (Miles & Huberman, 1994). By using multiple data sources, including supplier surveys, follow-up interviews and third-party reports, the study was able to cross-verify findings.

External validity, on the other hand, assesses whether the findings of a study can be generalized to other contexts (Findley, et al., 2021). In this research, efforts were made to enhance external validity by selecting a diverse sample of respondents. Suppliers were chosen based on various criteria, including geographical location.

4. Findings

This chapter outlines the findings from the research conducted. In paragraph 4.1, the sources of suppliers' emissions will be analysed. The second paragraph discusses emissions associated with the transport phase. The third paragraph compares the supply chain and supplier emissions, and paragraph 4.4 discusses the drivers influencing supplier and supply chain emissions.

4.1. Supplier emission sources

This section aims to answer the first empirical research question: '*What are the primary sources of GHG emissions at suppliers within the automotive industry?'* In this section, the most important production processes of first-tier suppliers at DAF Trucks will be discussed.

DAF Trucks collaborates with hundreds of first-tier suppliers, and eighty first-tier suppliers provide metal components. These components are essential to truck manufacturing, as a substantial portion of a truck comprises steel, cast iron, and aluminium. More than 75% of a truck is made of these metals, distributed as follows: 48.6% steel, 24.5% cast iron, and 4.7% aluminium (DAF Trucks N.V., 2023).

To produce and use these products, first-tier suppliers provide a variety of products, from solely flat steel, that DAF Trucks will further process in its own factories, to whole door panels, decorative strips, cylinder blocks, and flywheels. First-tier suppliers use several production methods to produce these products, such as flat steel production, forging, casting, and stamping. In the following paragraphs these production methods will be explained further.

Flat steel

Flat steel is solely produced by EU-based suppliers. DAF Trucks has four large flat steel providers, and during the research three of these suppliers were analysed.

Currently, the production of flat steel is a highly carbon-intensive process. According to Flat Steel Mill A Europe, 8% of total emissions in their country are attributed to their company and the flat steel production process.

As discussed in chapter two, the production of flat steel consists of a few steps. The primary raw materials for steel production are iron ore and coal. Flat Steel Mills B and C primarily source iron from non-EU countries, such as Australia, South Africa, and Canada, while Flat Steel Mill A mainly utilises iron ore from government-owned mines. Coals are mainly sourced within the EU.

The production of flat steel starts with the mining of iron ore, coking coal, and limestone. The coking coal is heated in coke ovens to produce coke, while the iron ore undergoes pelletizing and sintering in preparation for the blast furnace (BF). Inside the BF, coke is burned at high temperatures, producing carbon monoxide (CO) that reduces the iron ore to molten iron (pig iron). Steel is produced using either a Basic Oxygen Furnace (BOF), which converts pig iron to steel, or an Electric Arc Furnace (EAF), which uses electricity and results in lower CO_2e emissions by bypassing the chemical process that involves coal and iron ore. Flat Steel Mills B and C solely rely on BF-BOF, while Flat Steel Mill A has recently opened its first EAF factory. All three companies are investing in new EAFs, with costs running into the hundreds of millions of euros. Besides the financial costs associated with investing in this new technology, a problem arises with the production of energy needed for these furnaces. As a result, all three companies are collaborating with electricity providers and the government to explore using green hydrogen in the future. The final steps in the production process of flat steel include refining the steel, casting, and rolling.

The emissions breakdown data from the interviews and the in-depth analysis of Flat Steel Mill C revealed that 70-80% of the total scope 1 emissions stem from the BF-BOFs. Overall, the production process accounts for approximately 80% of all emissions, while mining the raw material contributes around 20%. The emissions from other processes are negligible in comparison. All suppliers provided specific data on CO_2e emissions per tonne of end product supplied to DAF Trucks, as summarised in the table below.

Company	Average tonnes CO_2e/tonne product
Flat Steel Mill A	2.1
Flat Steel Mill B	2.4
Flat Steel Mill C	2.2

Table 3: CO_2e emissions per tonne of finished product flat steel production.

As shown, Flat Steel Mill A has the lowest average CO_2e emissions per tonne product, while Flat Steel Mill C has the highest average emissions. The difference in emissions is primarily due to using more efficient processes and the opening of the new EAF plant at Flat Steel Mill A.

During the in-depth analysis of Flat Steel Mill C, additional data was found regarding emissions throughout the life cycle of flat steel. The table below includes several production processes at Flat Steel Mill C. A key finding from this analysis is the significant recycling benefit that arises when reusing materials rather than utilising new raw materials.

Product	Average tonnes CO_2e/tonne product	Recycling benefit (tonnes CO_2e/tonne product)
Cold rolled steel	2.37	-1.47
Pickled hot rolled coil	2.2	-1.38
Hot dip galvanised steel coil	2.37	-1.45

Table 4: CO_2e emissions per tonne of finished product of Flat Steel Mill C.

Aluminium Casting

Aluminium casting is a manufacturing process in which liquid aluminium is poured into a mould to create a specific shape or component. A wide variety of products for DAF Trucks are produced via this method, such as the flywheel housing and the headlamp brackets. During this research, four aluminium casting companies were analysed, two of which are based in Europe and two based in non-European countries.

Although several methods for aluminium casting exist, all the companies studied predominantly utilise high-pressure die casting (HPDC) as the primary casting method.

This method is particularly advantageous for achieving high production rates. In HPDC, liquid aluminium is poured into a chamber, where a piston rapidly accelerates, transporting the molten aluminium into a steel die to form the desired shape. While the casting process does not contribute significantly to emissions, heating the aluminium prior to casting is responsible for the highest scope 1 emissions at the suppliers, accounting for approximately 60% of total emissions on average. Gas is the primary source for the heating process.

When considering total emissions, upstream emissions constitute the largest share, primarily linked to bauxite mining. Recycling offers a much more sustainable solution, requiring only 5% of the total energy compared to primary aluminium production (Ding et al., 2012). All four companies highlighted the importance of using recycled aluminium in manufacturing. Nevertheless, the total percentage of recycled aluminium varied significantly, ranging from 30% to 96%. The availability of recycled aluminium and the quality needed to meet the suppliers' standards, require the use of non-renewable material.

> *"We use approximately 96% recycled aluminium and 4-5% primary aluminium due to quality requirements." (Alu. Casting A Europe)*

The table below presents the total emissions per tonne of end product for the analysed companies. It is important to note that Alu. Casting C Asia was unable to present any emissions data and Alu. Casting D Asia limited its assessment to scope 1 and scope 2 emissions. These limitations complicate direct comparisons with Alu. Casting A and B Europe. The lack of data from Alu. Casting D Asia can be attributed to its reliance on second-tier suppliers and the absence of data from Alu. Casting C Asia is due to its geographical location and a lack of regional regulations. These drivers will be further discussed in paragraph 4.4.

Company	Average tonnes CO_2e/tonne product
Alu. Casting A Europe	5.1
Alu. Casting B Europe	7.6

The primary difference between the emissions of Alu. Casting B and A, is that alu. Casting B utilises a significantly more comprehensive assessment of its scope 3 emissions than Alu. Casting A.

Table 5: CO_2e emissions per tonne of finished product aluminium casting.

Forgings

Forging is a manufacturing process that shapes metal into a desired form through the application of forces. It is particularly valued for producing strong, durable components. Products made via this production method for DAF Trucks include crankshafts, front axle beams, and steering knuckles. Four forgings companies, consisting of two EU and two non-EU suppliers, were analysed during this research.

The forging process begins with a steel bar, which is sourced from steel suppliers using similar processes to those involved in producing flat steel. Once a steel bar is received, it is heated to temperatures exceeding 1000 degrees Celsius. After heating, the material is shaped into the desired form by applying pressure and subsequently undergoes a cooling process. Additional steps, such as machining and heat treatment, further refine the final product.

The heating phase is the most energy-intensive aspect of the forging process and is a significant contributor to CO_2e emissions when energy originates from non-renewable sources. Forgings supplier D highlighted that their induction billet heating accounts for approximately 60% of their total internal emissions.

> *“Our induction Billet Heating accounts for approximately 60% of our total internal emissions.” (Forgings D Asia)*

In addition to the energy consumed during the heating phase, other electrical usages throughout the forging process also contribute to emissions. Forgings C Asia has identified purchased electricity as one of the primary contributors to their overall emissions, alongside scope 3 emissions associated with the raw materials used in the forging process.

Unfortunately, Forgings D Asia is the only company that has provided a comprehensive account of its total CO_2e emissions, including scope 1, scope 2, and upstream scope 3 emissions. Forgings A Asia and Forgings C Asia only presented data solely for scope 1, and scope 2 emissions, and Forgings B Europe was unable to supply emissions data related to its forging processes.

Company	Average tonnes CO_2e/tonne product	Included emissions
Forgings A Asia	2.1	Scope 1 and scope 2
Forgings C Asia	1.3	Scope 1 and scope 2
Forgings D Asia	3.1	Scope 1, scope 2 and scope 3

'Forgings D Asia' reported 60% of their total emissions fall within scope 3 upstream. When extrapolating this percentage to 'Forgings A Asia' and 'Forgings C Asia', their CO_2e emissions per tonne of product would be estimated at 6.8 and 4.2, respectively. However, making a direct comparison among these companies is challenging due to the differing energy sources utilised in their operations. Specifically, 'Forgings D Asia' employs a higher proportion of renewable energy in its production processes compared to both 'Forgings C Asia' and 'Forgings A Asia'.

Table 6: CO_2e emissions per tonne of finished product forgings.

Stampings

Stamping is a manufacturing process used to transform flat steel into specific shapes and components by feeding flat sheets of steel into a die. The metal is pressed into the die using significant force. Three stamping suppliers were analysed during the research, making various products such as roof panels, side panels, and engine covers.

Within these suppliers, the stamping process consumes the most energy, especially when the product requires preheating, accounting for approximately 70% of total scope 1 and 2 emissions. However, as noted by Stampings C Europe, this represents only a tiny amount of total emissions when also considering scope 3 emissions. According to Stampings C Europe and Stampings A Europe, scope 3 emissions, primarily associated with the BF-BOF process, account for more than 90% of total emissions.

> *“Within our company, our emissions are relatively low, compared to the total supply chain. Our scope 3 emissions are estimated at 96% of total emissions” (Stampings C Europe)*

All three companies provided data on their total scope 1, scope 2, and scope 3 emissions. See the table below.

Company	Average tonnes CO_2e/tonne product
Stampings A Europe	2.6
Stampings B Europe	2.3
Stampings C Europe	3.0

Table 7: CO_2e emissions per tonne of finished product stampings.

Iron casting

Iron casting is a process in which molten iron is poured into a mould to create a desired shape or component. The initial step in the iron casting process consists of making a mould, commonly made from sand. This method and use of sand was also utilised by Iron Casting A Europe, the second company examined in more detail during a company visit. The iron is melted using a crucible melting furnace or a cupola furnace and poured into the mould. This iron-casting method is used for parts such as cylinder blocks, cylinder heads, and flywheels.

The two companies examined vary in their use of recycled materials. Iron Casting B Europe uses 80% recycled material, while Iron Casting A Europe utilises exclusively recycled material. The casting process requires significant energy to melt the iron, and the energy consumed largely determines the total CO_2 emissions with production. Iron Casting A Europe utilises a combination of coal, gas, and renewable energy (60.4%). Iron Casting B Europe uses 36.6% renewable energy. In contrast to castings, forgings, and aluminium casting, the total emissions of iron casting are relatively balanced between scope 1 and scope 2, and scope 3 emissions. The table below shows the average emissions of Iron Casting A Europe. Unfortunately, Iron Casting B Europe was not able to provide data on all of its scopes.

Company	Average tonnes CO_2e/tonne product
Iron Casting A Europe	1.6

Table 8: CO_2e emissions per tonne of finished product iron casting.

Conclusion

The emission profiles of the various production processes examined in this research reveal considerable variation across each process. Below is an overview of the emissions associated with the different production methods, based on the average emission reported by suppliers that provided data on scope 1, scope 2, and scope 3 upstream emissions. As shown in this table, the highest CO_2e emissions occur in scope 3 for aluminium casting, forgings, and stampings. In contrast, the highest emissions for flat steel are observed in scope 1, while iron casting emissions are more balanced across scopes. A more detailed breakdown of emissions per supplier, and an overview of the data sources used, is provided in Appendix 9. Appendix 10 presents an overview of which companies measure emissions across all scopes.

	Scope 1	Scope 2	Scope 3 upstream
Alu Casting	14%	10%	76%
Flat Steel	63%	2%	29%
Forgings	10%	21%	60%
Stampings	2%	3%	95%
Iron Casting	39%	17%	44%

Included companies are: ‘Alu. Casting A Europe’, ‘Alu. Casting B Europe’, ‘Flat Steel Mill A Europe’, ‘Flat Steel Mill B Europe’, ‘Flat Steel Mill C Europe’, ‘Forgings D Asia’, ‘Stampings A Europe’, ‘Stampings C Europe’, and ‘Iron Casting A Europe’ (other companies did not provide scope 1, scope 2, and scope 3 upstream emissions.)

Note: percentage do not total 100% due to the influence of scope 3 downstream emissions.

Table 9: Average percentage of CO_2e emissions per production process.

Appendix 11 contains a comprehensive overview of the investments and material usage of the analysed companies. It can be concluded that a significant portion of emissions occur in scope 3 upstream. As several suppliers demonstrated, using secondary materials can significantly reduce emissions. Additionally, the type of energy used is a significant factor influencing emissions levels. Finally, the technology employed, and the efficiency of the production processes also play a significant role in determining overall emissions.

4.2. Supply Chain emissions

This section aims to answer the second empirical research question: *‘What are the primary sources of GHG emissions in the automotive industry’s supply chain?’* It will discuss the emissions of the first-tier suppliers regarding transport.

Transportation emissions, associated with the delivery of final products from suppliers to DAF Trucks are managed by several external transport providers, predominantly located within the Eindhoven region. Rather than being organised by the suppliers, the transportation logistics are primarily coordinated by DAF Trucks. This approach enables DAF Trucks to select transportation providers themselves, ensuring greater control directly. Transportation providers are selected based on several factors, such as their use of EURO 6 trucks. EURO 6 trucks are subject to stricter GHG emission standards compared to EURO 5 trucks (Grigoratos et al., 2019), making them a favourable choice. DAF Trucks exclusively relies on EURO 6 trucks provided by their transport partners. This raises the question of the potential use of electric trucks. However, at present, no electric trucks are utilised in the operations of DAF Trucks, highlighting an area of potential improvement in the near future.

To calculate transportation emissions associated with the products delivered from suppliers to DAF Trucks, a commonly used and appreciated method by the suppliers is the GHG Protocol (GHG Protocol, 2022). This method is the favourable method to measure companies’ emissions and calculate emissions on transportation. 12 of the 16 analysed companies mentioned the use of the GHG Protocol. When calculating GHG emissions, an important factor, though not always utilised, is the total weight of transport. Vehicle load has a significant impact on emissions (Wang et al., 2021). Other critical factors include the distance travelled and the emissions associated with the specific mode of transport. The formula presented below allows for an accurate calculation of total emissions.

$$\begin{aligned} & CO_2e\ emissions\ transport \\ & \qquad = \sum(mass\ of\ purchased\ goods\ (tonnes) \times distance\ travelled\ (in\ km) \\ & \qquad \times emission\ factor\ of\ transport\ type\ (kg\ CO_2e\ per\ tonne\ per\ km) \end{aligned}$$

Two sources were consulted to calculate the emission factor for each transport type: Ragon et al. (2021) and the “Guidelines For Measuring And Managing CO_2e emission From Freight Transport Operations” (2011). The table below summarises the average CO_2e emissions for several transport modalities.

Modality	CO_2e
Diesel truck (EURO 6)	0.057 kg CO_2e/tonne transport/km
Boat (bunker fuel)	0.013 kg CO_2e/tonne transport/km
Train	0.022 kg CO_2e/tonne transport/km
Plane	0.602 kg CO_2e/tonne transport/km

Table 10: CO_2e emissions of transport modalities.

Table 11 summarises the total emissions per shipment per supplier to DFA Trucks in 2024. It also presents the total emissions up to October 31, 2024, along with an extrapolation for the remainder of the year. The extrapolation was necessary due to the unavailability of data for the period between November 1, 2024, and December 31, 2024. The extrapolated figures estimate of the total emissions for the entire year.

The results reveal a clear trend: suppliers located further from DAF Trucks’ operations generally exhibit higher emissions, particularly when air transport is involved, leading to a notable spike in total emissions. Appendix 12 provides a more detailed overview of transport emissions, including transport weights, distances, and modalities.

	Average kg CO_2e emission per shipment	Total Tonnes CO_2e emission 01-01-2024 until 31-10-2024	Total Tonnes CO_2e emission Extrapolated for year 2024
Alu. Casting B Europe*	18	3	4
Forgings D Asia**	5,019	527	632
Iron Casting A Europe*	462	551	661
Alu. Casting A Europe*	735	46	56
Alu. Casting C Europe**	1,271	53	64
Stampings A Europe*	423	602	723
Iron Casting B Europe*	313	68	82
Stampings C Europe*	545	309	371
Forgings B Europe*	251	50	60
Forgings C Europe**	2,148	466	559
Flat Steel Mill A Europe***	1,696	848	1,018
Alu. Casting D Asia**	962	42	51
Flat Steel Mill C Europe ***	392	177	212
Forgings A Asia**	2,929	434	520
Stampings B Europe*	155	72	86

*Calculated based on archival data.

**Calculated based on a combination of archival data and the questionnaire.

***Calculated based on the questionnaire.

****Unfortunately, the calculation could not be made for 'Flat Steel Mill B Europe', due to a lack of available data.

Table 11: CO_2e emission of transport.

The non-European suppliers mainly rely on a combination of boat and truck transport for their shipments. Although the average CO_2e emissions associated with boat transport are significantly lower compared to truck transport, non-EU suppliers experience higher average emissions per shipment due to the longer travel distances involved. From the analysis above, three sources of emissions from transportation can be identified: travel distance, transport modality, and energy source as a potential shift to other energy sources in the near future.

4.3. Supplier vs Supply Chain Emissions

This section examines the third empirical research question: *'How do supplier emissions compare to supply chain emissions in terms of their contribution to overall*

GHG emissions within the automotive industry?' A finding of this research is the differentiation between emissions originating from supplier processes and those associated with supply chain activities. The data collected on supplier and supply chain emissions highlight a disparity between these sources. On average, 97% of the emissions, as analysed via the suppliers, are attributed to the supplier processes, whereas only 3% are linked to supply chain activities. A comprehensive analysis of the total emissions of suppliers in production and transportation is provided in Appendix 13.

	% in production	% in transportation
CO_2e emissions	97	3
Companies included in the analysis: 'Alu. Casting B Europe', 'Forgings D Asia', 'Iron Casting A Europe', 'Alu. Casting A Europe', 'Stampings A Europe', 'Forgings C Asia', 'Flat steel mill A Europe', 'Alu. Casting D Asia', 'Flat Steel Mill C Europe', 'Forgings A Asia', and 'Stampings B Europe'		

Table 12: Percentage of emissions in production process and transportation.

Another notable finding relates to the distribution of emissions within suppliers. On average, 53% of total supplier emissions are attributed to scope 3 upstream emissions. However, this percentage should be interpreted with caution due to significant limitations in the data. Not all companies included in this study measured their scope 3 upstream emissions, and this conclusion is based on only eight suppliers, reducing the reliability of these findings.

	% at supplier	% in scope 3 upstream for suppliers
CO_2e emissions	47	53
Companies included in analysis 'Alu. Casting B Europe', 'Forgings D Asia', 'Iron Casting A Europe', 'Alu. Casting A Europe', 'Stampings A Europe', 'Flat Steel Mill A Europe', 'Flat Steel Mill C Europe', and 'Flat Steel Mill B Europe'		

Table 13: Distribution of supplier emissions by scope 1 and scope 3.

4.4. Factors influencing supplier and supply chain emissions

This section addresses the fourth and fifth empirical research questions: *'What are the key factors influencing GHG emissions at suppliers within the automotive industry?'* and *'What are the key factors influencing GHG emissions in the automotive industry's supply chain?'* The analysis identified a range of factors that influence GHG emissions, both in the present and potentially in the near future. These factors contain supplier-specific factors, supply chain factors, and overarching factors affecting both sources of supplier emissions and/or supply chain emissions. The figure below presents a schematic overview, including the sources of emissions, as discussed in the paragraphs above.

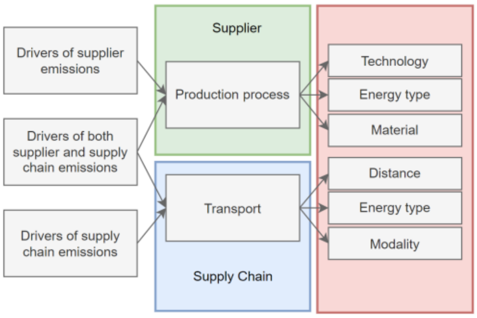


Figure 4: Distinction of factors influencing supplier, supply chain or both supplier and supply chain emissions.

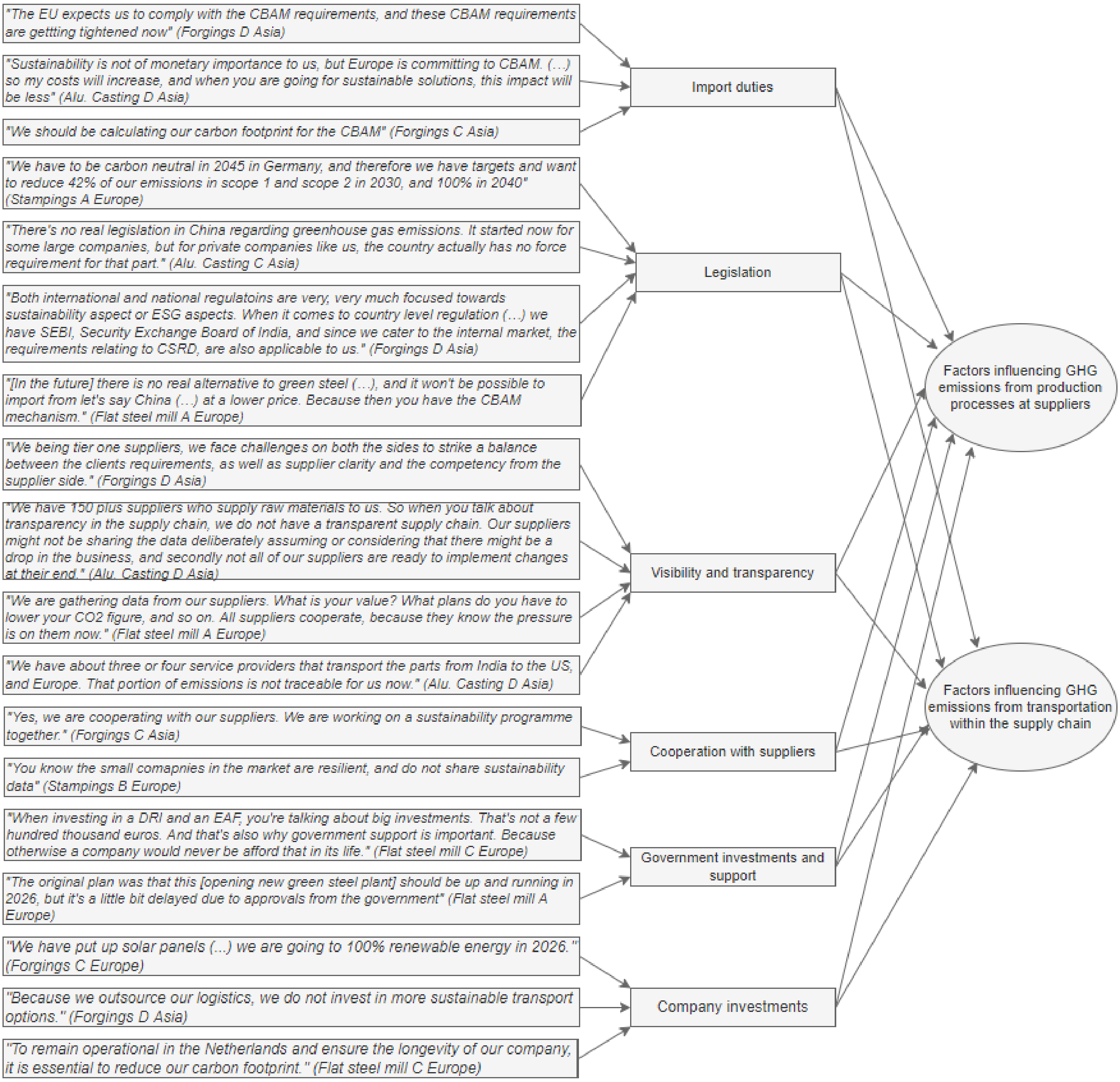
The table below summarises all the factors or drivers of the sources of emissions at suppliers or within the supply chain. Factors influencing both supplier and supply chain are discussed in section 4.4.1, factors influencing solely supplier emissions in section 4.4.2, and factors influencing supply chain emissions in section 4.4.3.

	Supplier	Supply Chain
Source	Production process - Technology - Energy type - Material	Transportation - Distance - Energy type - Modality
Influence	Import duties Legislation Government investments and support Company investments Visibility/transparency Cooperation between suppliers Public pressure Supplier size Customer pressure Supplier practices	Import duties Legislation Government investments and support Investments Visibility/transparency Cooperation between suppliers Geographical location Transport optimisation

Table 14: Drivers influencing sources of emissions at supplier and in the supply chain.

4.4.1. Factors influencing both supplier and supply chain emissions

Several key factors/drivers impact emissions at both the production process at suppliers and transportation in the supply chain have been identified. These factors are summarised and visualised with supporting quotes from suppliers in the figure below.



"The EU expects us to comply with the CBAM requirements, and these CBAM requirements are gettting tightened now" (Forgings D Asia)

"Sustainability is not of monetary importance to us, but Europe is committing to CBAM. (…) so my costs will increase, and when you are going for sustainable solutions, this impact will be less" (Alu. Casting D Asia)

"We should be calculating our carbon footprint for the CBAM" (Forgings C Asia)

"We have to be carbon neutral in 2045 in Germany, and therefore we have targets and want to reduce 42% of our emissions in scope 1 and scope 2 in 2030, and 100% in 2040" (Stampings A Europe)

"There's no real legislation in China regarding greenhouse gas emissions. It started now for some large companies, but for private companies like us, the country actually has no force requirement for that part." (Alu. Casting C Asia)

"Both international and national regulatoins are very, very much focused towards sustainability aspect or ESG aspects. When it comes to country level regulation (…) we have SEBI, Security Exchange Board of India, and since we cater to the internal market, the requirements relating to CSRD, are also applicable to us." (Forgings D Asia)

"[In the future] there is no real alternative to green steel (…), and it won't be possible to import from let's say China (…) at a lower price. Because then you have the CBAM mechanism." (Flat steel mill A Europe)

"We being tier one suppliers, we face challenges on both the sides to strike a balance between the clients requirements, as well as supplier clarity and the competency from the supplier side." (Forgings D Asia)

"We have 150 plus suppliers who supply raw materials to us. So when you talk about transparency in the supply chain, we do not have a transparent supply chain. Our suppliers might not be sharing the data deliberately assuming or considering that there might be a drop in the business, and secondly not all of our suppliers are ready to implement changes at their end." (Alu. Casting D Asia)

"We are gathering data from our suppliers. What is your value? What plans do you have to lower your CO2 figure, and so on. All suppliers cooperate, because they know the pressure is on them now." (Flat steel mill A Europe)

"We have about three or four service providers that transport the parts from India to the US, and Europe. That portion of emissions is not traceable for us now." (Alu. Casting D Asia)

"Yes, we are cooperating with our suppliers. We are working on a sustainability programme together." (Forgings C Asia)

"You know the small comapnies in the market are resilient, and do not share sustainability data" (Stampings B Europe)

"When investing in a DRI and an EAF, you're talking about big investments. That's not a few hundred thousand euros. And that's also why government support is important. Because otherwise a company would never be afford that in its life." (Flat steel mill C Europe)

"The original plan was that this [opening new green steel plant] should be up and running in 2026, but it's a little bit delayed due to approvals from the government" (Flat steel mill A Europe)

"We have put up solar panels (...) we are going to 100% renewable energy in 2026." (Forgings C Europe)

"Because we outsource our logistics, we do not invest in more sustainable transport options." (Forgings D Asia)

"To remain operational in the Netherlands and ensure the longevity of our company, it is essential to reduce our carbon footprint." (Flat steel mill C Europe)

Figure 5: Key drivers influencing supplier and supply chain emissions, supported by quotes.

Import duties are of significant influence in reducing GHG emissions in both production and transportation. The European Union introduced the Carbon Border Adjustment Mechanism (CBAM) to encourage cleaner industrial practices for non-EU members and align imported products with the EU carbon pricing under the Emission Trading System (ETS). This mechanism specifically targets carbon-intensive products, such as iron and steel, and entirely comes into effect in 2026. Due to the price imposed on imports under the CBAM, companies are increasingly motivated to adopt more sustainable practices. This is essential for maintaining competitiveness and remaining attractive to European companies such as DAF Trucks, who are under pressure to meet stricter environmental standards. As a result, suppliers outside the European Union are investing in cleaner production methods and renewable energy sources.

In addition to import duties, the legislation also influences suppliers' sustainability initiatives. The EU has enacted policies to reduce emissions, creating a regulatory environment that encourages EU-based suppliers to prioritise sustainability in their production and transportation processes. Conversely, non-European countries enforce less stringent environmental regulations, resulting in lower sense of urgency among non-European suppliers to invest in emissions reduction strategies.

Enhanced visibility and transparency within the supply chain are also critical to achieving reductions in GHG emissions. Greater visibility within the supply chain enables more effective collaboration among stakeholders and facilitates accurate tracking and reporting of emissions. This transparency and cooperation are essential not only for advancing sustainability objectives but also for managing and mitigating emissions across the entire supply chain. Unfortunately, as mentioned in the previous sections, several suppliers face challenges in achieving sufficient visibility within their supply chains.

Governmental support and investments also influence the transition to sustainable practices. For example, Flat Steel Mill A has received 1.45 billion SEK (approximately 127 million euros) to develop and produce fossil-free steel, representing a substantial step toward reducing emissions. Similarly, Flat Steel Mill C has emphasised the necessity of governmental support in enabling investments in green technologies. This assistance is especially critical for flat steel suppliers, as their operations are characterised by high emissions (scope 1) and require substantial capital to implement new and clean technologies.

Company investments made by companies to enhance sustainability are also vital to achieving reductions in GHG emissions. Many suppliers reported that long-term sustainability strategies hinge on significant financial commitments to clean energy, energy-efficient processes, and low-carbon production methods. These investments facilitate compliance with evolving regulatory requirements and align with growing consumer and market demands for environmentally responsible products. Appendix 11 provides an overview of all the future investments mentioned by the suppliers analysed in this study.

4.4.2. Factors influencing supplier emissions

Several factors only impact supplier emissions. See the figure below.

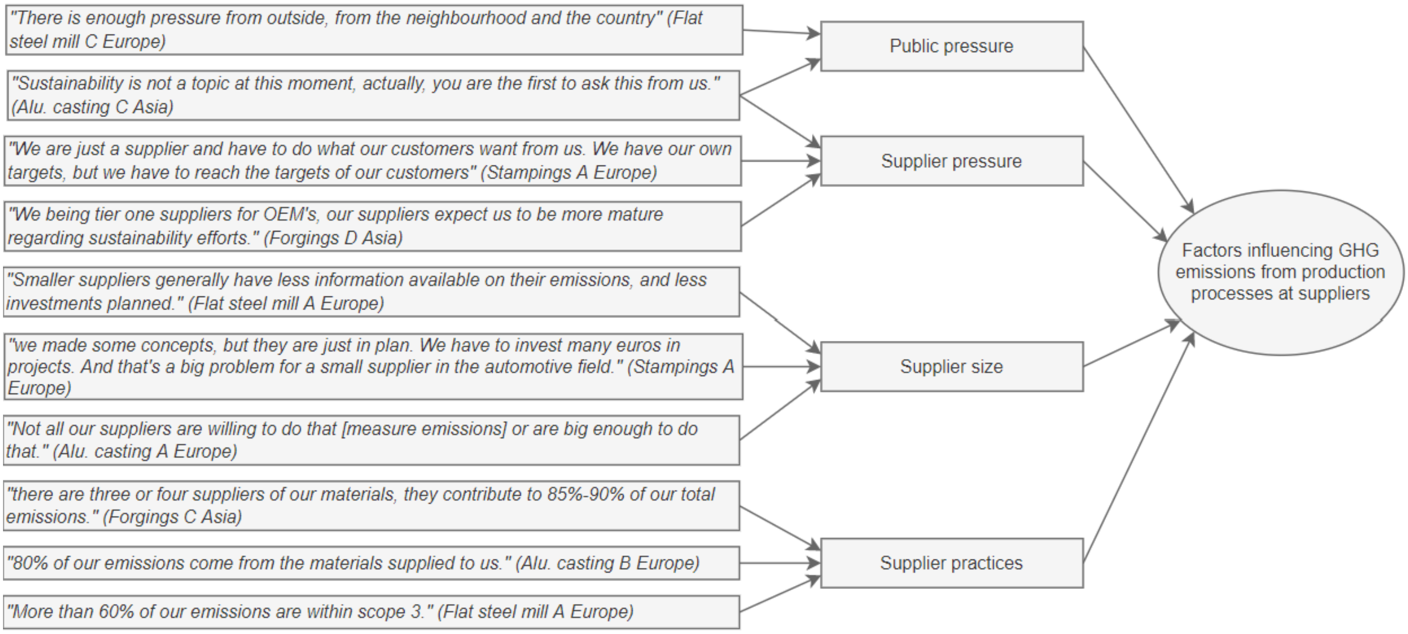


Figure 6: Key drivers influencing supplier emissions, supported by quotes.

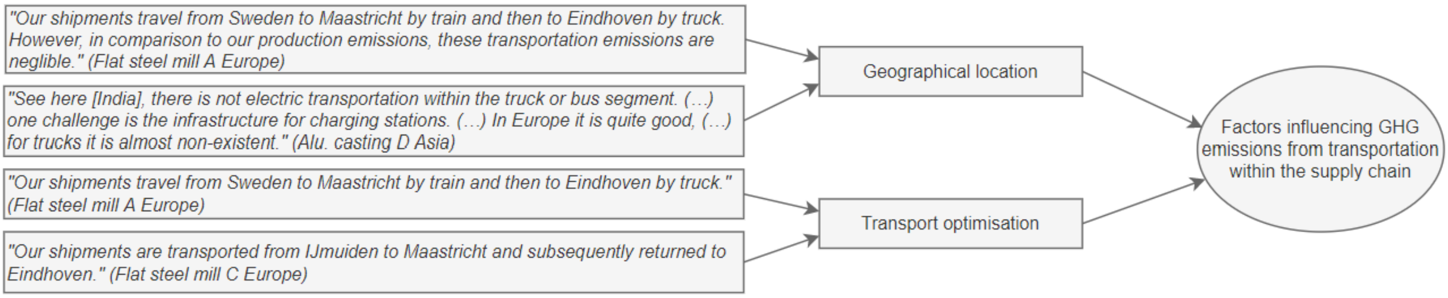
A significant driver of supplier emissions is pressure applied by the public and clients. Several suppliers emphasised that measuring is often a direct requirement from their customers. Particularly mentioned by the non-European suppliers. EU-based suppliers, in contrast, frequently mentioned the desire to internally promote the environment. Public pressure also plays an important role, particularly for flat steel manufacturers in the EU, where public awareness of environmental and health issues is high. This created additional expectations from companies to reduce their carbon footprint and prioritise sustainability in their business model.

The size of suppliers also impacts GHG emission strategies. Smaller suppliers often lack visibility into their supply chain, particularly regarding emissions and future sustainability plans. This lack of visibility, highlighted in the previous section, makes it more challenging for smaller suppliers to measure and reduce their emissions effectively, as they often lack the resources and infrastructure. In contrast, larger suppliers generally possess more advanced processes and capabilities, granting them better insights into supply chain emissions and enhancing their ability to implement effective emission reduction strategies.

Suppliers' emissions are heavily influenced by the practices of their upstream suppliers, particularly those providing raw material. As discussed in chapter 4.3, several sources substantially impact on the total emissions within a supply chain. This interdependence underscores the importance of collaboration and alignment between suppliers and their upstream partners.

4.4.3. Factors influencing supply chain emissions

Two key drivers specific to transport-related emissions are illustrated in the figure below. One prominent factor influencing supply chain emissions is the geographical location of suppliers. This factor impacts emissions for several reasons. First, longer distances between suppliers and clients increase emissions, as discussed in paragraph 4.2. Second, the geographical location can affect the feasibility of adopting alternative, low-emission shipping modes. For example, while electric trucks are becoming increasingly viable within Europe due to shorter distances and more developed infrastructure, their adoption may be less feasible in regions such as India, where longer distances and limited electric infrastructure present challenges.



"Our shipments travel from Sweden to Maastricht by train and then to Eindhoven by truck. However, in comparison to our production emissions, these transportation emissions are neglible." (Flat steel mill A Europe)

"See here [India], there is not electric transportation within the truck or bus segment. (…) one challenge is the infrastructure for charging stations. (…) In Europe it is quite good, (…) for trucks it is almost non-existent." (Alu. casting D Asia)

"Our shipments travel from Sweden to Maastricht by train and then to Eindhoven by truck." (Flat steel mill A Europe)

"Our shipments are transported from IJmuiden to Maastricht and subsequently returned to Eindhoven." (Flat steel mill C Europe)

Figure 7: Key drivers influencing supply chain emissions, supported by quotes.

Another key driver is transport optimisation, which has a key impact on supply chain emissions. For instance, air freight is notably more emissions-intensive compared to maritime shipping. However, not all transport routes are optimised, leading to inefficiencies that contributing to higher emissions. An example of this inefficiency can be observed by Flat Steel Mills C, where flat steel is first transported from northern Europe to Maastricht, only to be subsequently shipped to Eindhoven, thereby unnecessarily increasing transport distances.

5. Conclusion and discussion

This chapter begins by discussing the findings, followed by an exploration of the theoretical contributions, an examination of limitations and future research directions, and ends with the managerial implications and a conclusion.

5.1. Discussion

This research highlights production processes, consisting of technology, energy types, and material usage, as the primary sources of GHG emissions. These findings align with previous research of Govindan et al. (2014) and Srivastava (2007), which highlight the importance of green manufacturing processes to become more sustainable, as well as the studies by Xue et al. (2024) and Gorman et al. (2022) which highlight the influence of production and material usage on emissions.

During this research, transportation was identified as the primary source of emissions within the supply chain. These emissions, mainly influenced by distance, energy type, and modality used, support the existing literature of Barberio Mariano et al. (2017) and Heinen et al. (2019), who emphasise the role of transportation in emissions generation. However, this literature contrasts with the findings of Ragon et al. (2021), who argue the critical role of fuel sources in determining emissions. In the current context, however, the fuel source is not a significant differentiator, as road transportation is mainly conducted via diesel-powered trucks, and maritime shipping relies on bunker fuel, leaving little room for fuel-related emission variation.

The findings of this study indicate that emissions from production processes serve as the primary contributor to overall emissions, supporting the conclusions of Takayabu et al. (2019), Worrel et al. (2008), and McKinnon & Piecyk (2012), which suggest that emissions from transportation are comparatively less significant. This study extends the work of Hertwich and Wood (2018), who demonstrated the dominating effect of upstream production processes by providing a more detailed breakdown of emissions on different production processes. However, this research diverges from current literature that emphasises logistics optimisation as a starting point of emissions reduction (e.g., Gan et al., 2018) by demonstrating the minor role of transport emissions compared to production processes.

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Additionally, this study contributes to the understanding of emissions at the supplier level, particularly emphasising the substantial impact of upstream processes, which fall under scope 3 emissions. This finding builds on research conducted by Mahapatra et al. (2021), who called for a more extensive scope 3 analysis.

Furthermore, this study advances the understanding of key drivers influencing GHG emissions, drawing on the work of Ahi. et al. (2015) to overcome the obstacle of identifying emission factors. This research revealed several drivers influencing supplier and supply chain emissions: import duties, legislation, visibility and transparency, cooperation between suppliers, government investments and support, and company investments. Whereas previous research explained the impact of import duties on emissions in a specific country (e.g. Thammarak & Witthaya, 2021) and trade restrictions on sustainable supplier management (Patil et al., 2022), this study positions these factors within a specific industry. The role of legislation complements the research of Ioannau and Seraeim (2014), who highlighted the impact of regulations on production and transport emissions. The influence of investments on GHG emissions further aligns with the findings of Kwilinski et al. (2024), and the identification of transparency builds on the research of Bray et al. (2011), Osburg et al. (2020), and Zhao et al. (2012).

Several specific drivers for supplier-related emissions were identified. The impact of supplier size on emissions is also discussed by Gallo and Christensen (2011), who found that larger firms are typically more adept at implementing sustainable practices compared to smaller firms. The influence of customer pressure is consistent with the work of Seuring & Müller (2008) and Gualandris et al. (2015), which reviews the impact of customer pressure on sustainable management. The impact of public pressure elaborates on the work of Lee (2011), who emphasised the role of public pressure in promoting green logistics practices by extending the understanding to production processes. Finally, geographical location and transport optimisation are unique drivers of supply chain emissions identified in this study. These findings support and extend the research of Ahi et al. (2015), who emphasised the role of emissions in global sourcing.

5.2. Theoretical contributions

This research introduces a novel 2x2 emission framework that offers sourcing strategies based on the intensity of scope 3 emissions. The framework distinguishes between high and low supply chain emissions in the rows and high and low supplier emissions in the columns.

	High supplier emissions	**Low supplier emissions**
High supply chain emissions	Most efficient supplier within local supply chain	Local supply chain
Low supply chain emissions	Most efficient supplier globally	Focus on other factors

Table 15: Sourcing strategy framework.

The framework suggests that when supply chain emissions are low, but supplier emissions are high, companies should prioritise sourcing the most efficient suppliers, with the lowest emissions in their production process, on a global scale. Due to the high impact of supplier emissions and the low impact of supply chain emissions, distance to suppliers is of less importance. Conversely, when supply chain emissions are high, but supplier emissions are low, companies should focus on local sourcing to mitigate the impact of transport-related emissions. If both the supplier and supply chain emissions are high, companies should focus on identifying the most efficient supplier (lowest production emissions) within a localised supply chain, ensuring close proximity to the company. Finally, when supplier and supply chain emissions are low, companies can shift their focus to other strategic factors, such as price or quality. While this framework builds on existing knowledge on scope 3 emissions, it extends by providing a practical tool for selecting suppliers, based on the emissions within transportation and at suppliers.

5.3. Limitations and future research directions

The generalisability of this study is subject to certain limitations. Because the study focuses on the automotive industry, its findings may not fully extend to other industries due to the unique characteristics of this sector. The automotive industry relies on carbon-intensive materials and operates through a highly globalised supply chain. These features may not apply to other industries with less emissions-intensive inputs or more localised supply chains. Additionally, not all the identified drivers may be generalisable to other sectors or regions. For example, regions with less stringent regulations may experience a diminished impact from import duties. Furthermore, the study's supplier selection, based on suppliers' significant revenue contributions to DAF Trucks, may have resulted in a selection bias by underrepresenting smaller suppliers or suppliers from other regions. Future research could address these limitations by expanding the sample size to include a broader range of suppliers or by comparing the suppliers across multiple industries.

Another limitation concerns the challenges encountered in measuring supplier emissions due to incomplete data. The lack of comprehensive data hinders the ability to establish definitive causal relationships between the identified drivers and emission outcomes. Moreover, the interviews conducted with suppliers after the survey may have introduced confirmation bias, as the focus of the interview questions could have been influenced by pre-existing expectations. Lastly, while efforts were made to mitigate response bias, the sensitivity of the information provided by suppliers may have influenced their responses. As such, the internal validity of this study is moderate, with key strengths in the systematic approach and the use of multiple data sources but limitations due to incomplete data and several potential biases. The external validity is limited as well, given the industry-specific focus on a sector characterised by high emissions.

To test the proposed framework, future research should focus on further exploring its components, using quantitative methods. Whereas this study provides insights into high supplier emissions and low supply chain emissions in the automotive sector, it is important to assess the framework's applicability across different sectors, with diverse supply chains. Additionally, future studies should explore the drivers influencing emissions in more depth, examining how these drivers impact emissions in more detail.

5.4. Managerial implications

Managerial implications DAF Trucks

This study identifies production processes as the primary source of emissions. To reduce its environmental footprint, DAF Trucks should prioritise partnerships with suppliers utilising low-emission production processes. Since transportation emissions are relatively less significant compared to production emissions, efforts to reduce emissions, should continue to focus primarily on supplier emissions. Given that supplier emissions are high while supply chain emissions are low, DAF Trucks should focus on engaging the most efficient suppliers globally, as outlined in the framework.

Additionally, preference should be given to suppliers actively transitioning to low-emission production methods, incorporating significant amounts of recycled materials into their processes, or using renewable energy, as discussed in Appendix 11. Identifying average emissions per production process per supplier, measured in kilograms of CO_2e per kilogram of delivered product, provides DAF Trucks with a useful benchmark for evaluating and comparing suppliers based on their environmental performance. A cost-benefit analysis, which integrates both environmental and financial considerations will support the decision-making.

Transparency is a key driver of emission reduction strategies. DAF Trucks should encourage suppliers to disclose emissions data across their entire supply chain, promoting collaboration with tier-1, tier-2, and tier-3 suppliers. Implementing robust reporting and auditing mechanisms, including adopting the GHG Protocol, will ensure data accuracy, foster trust among suppliers, and enhance supplier engagement. Furthermore, collaboration with suppliers on sustainability initiatives will encourage knowledge sharing, accelerate innovation, and create a more sustainable supply chain.

General managerial implications

Companies across industries can benefit from adopting the framework introduced in this study. Emissions data can be used as a critical criterion to guide procurement decisions. Second, leveraging such frameworks enables organisations to benchmark supplier performance effectively, identify key areas for improvement, and align their sourcing strategies with sustainability objectives. Third, companies should analyse the factors influencing their emissions strategies, as identified in this research, to determine how these factors impact their operations and explore targeted methods for emissions reduction. Fourth, fostering collaborative initiatives is essential, especially since cooperation between suppliers is identified as a key factor influencing emissions. Involvement from multiple stakeholders, can facilitate the development of industry-wide sustainability efforts. Fifth, for industries reliant on carbon-intensive materials, companies should prioritise adopting renewable energy, invest in green production technologies, and increase the use of recycled materials. This aligns with the findings of this study, which demonstrated the significant reduction in carbon emissions achieved by using recycled materials.

5.5. Conclusion

In conclusion, this thesis has highlighted the critical role of supplier and supply chain factors in driving GHG emissions within the automotive industry, with a particular focus on DAF Trucks' metal component suppliers. By answering the research question, *“What supplier and supply chain factors within the automotive and metal supply chain are the main drivers of CO2e emissions?”* this study demonstrates that supplier emissions, particularly those arising from energy-intensive production processes, constitute the largest share of emissions in DAF Trucks’ supply chain, accounting for approximately 97% of total emissions. In contrast, transportation-related emissions contribute a relatively minor 3%. Furthermore, it was found that higher-tier suppliers, especially in industries such as steel and aluminium production, are the primary drivers of emissions, while suppliers specialising in stamping, aluminium casting, and forgings contribute only a small proportion of total emissions.

The research also emphasises the potential of secondary materials to reduce emissions. The use of recycled materials, demonstrated by reduced emissions, illustrate the importance of material circularity in sustainable supply chain practices.

This study contributes to the academic understanding of supply chain emissions by proposing a novel framework for sourcing strategies. This framework, presented in a 2x2 matrix, introduces an approach for evaluating sourcing decisions based on the intensity of supplier and supply chain emissions. Future research should further investigate this framework. Additionally, this study contributes and aligns with current literature identifying factors influencing GHG emissions. These factors attribute to supplier emissions, supply chain emissions, or both.

- Common drivers: Import duties, legislation, visibility/transparency, cooperation between suppliers, government investments, and company investments.
- Supplier-Specific drivers: Public pressure, client pressure, supplier size, and supplier practices.

- Supply chain-Specific Drivers: Geographical location and transport optimisation.

Despite its contributions, the study acknowledges certain limitations that may affect the validity and reliability of the findings. These limitations suggest the need for future research to validate the results and extend the findings to other industries.

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Appendices

Appendix 1: Scope emissions reporting among global truck manufacturers

The table below presents an overview of reported scope emissions among major truck manufacturers worldwide. All OEMs measure their scope 1, and scope 2 emissions, however only some companies fully measure their scope 3 emissions. This highlights a significant variance in emissions reporting among companies, underscoring differing levels of commitment to sustainable practices.

Company	Location	Scope 1 emissions	Scope 2 emissions	Scope 3 emissions	Scope 3 Cat 1, 3, 4 emissions	GHG protocol used
DAF Trucks	Europe	Yes	Yes	No	Yes	
Daimler	Europe	Yes	Yes	Partly	No	No
Ford	USA	Yes	Yes	Partly	No	Yes
Isuzu	Japan	Yes	Yes	Yes	Yes	Yes
Iveco	Europe	Yes	Yes	Yes	Yes	Yes
Mahindra	India	Yes	Yes	Partly	No	N/A
MAN	Europe	Yes	Yes	Partly	No	Yes
Renault	Europe	Yes	Yes	No	No	
Saic	China	Yes	Yes	Partly	No	N/A
Volvo	Europe	Yes	Yes	Partly	No	Yes

Table 16: Scope emissions reporting global truck manufactures.

Appendix 2: Reporting of scope emissions at metal companies

The table below presents an overview of reported scope emissions from various metal suppliers worldwide.

Supplier	Location	Sustainable report	Scope 1	Scope 2	Scope 3	GHG Protocol
Tata Steel	Europe	Yes	Yes	Yes	Yes	Yes
ArcelorMittal	Europe	Yes	Yes	Yes	No	Unknown
SSAB Swedish Steel	Europe	Yes	Yes	Yes	Yes	Yes
Thyssenkrupp	Europe	Yes	Yes	Yes	Yes	Yes
Ghial S.p.a.	Europe	No				
Aludyne Netherlands	Europe	No				
TVS Group	India	Yes	Yes	Yes	Partly	Unknown
Bharat Forge Limited	India	Yes	Yes	Yes	Partly	Yes
Musashi Bockenau	Japan	Yes	Yes	Yes	No	Yes
Ramkrishina Forgings	India	Yes	Yes	Yes	No	No
HÖRMANN Automotive	Europe	Yes	Yes	Yes	Partly	Yes
Voestalpine Automotive	Italia	Yes	Yes	Yes	Partly	No
LÄPPLE Automotive	Europe	No				
Fritz Winter Eisengiesserei GmbH & Co. Kg	Europe	No				
Guangdong Hongxing Precision Technology Corp	China	No				
Jost-Werke SE	Europe	Yes	Yes	Yes	No	Yes

Table 17: Sustainability report analysis.

Appendix 3: Overview of supplier questionnaire (EU suppliers)

Introduction:

Thank you for taking the time to complete this survey.

DAF Trucks is gathering insights from its suppliers to better understand and manage GHG emissions in its supply chain. Your responses will be valuable to this process and will be kept confidential.

Please note that the survey will only be submitted after the last question. If a question is unclear or not relevant to your company, you may leave it blank.

If you have any questions or comments, please reach out to Luc Raijmakers at luc.raijmakers1@daftrucks.com

Questions

	Question	Question type	Options
1	Please enter the name of your company.	Open question	
2	does your company measure its annual carbon footprint? Please select all that apply and provide the greenhouse gas (GHG) emissions in tonnes of CO_2e for 2023.	Multiple-Choice (multi-select) + open question.	(1) Yes, Scope 1 emissions. Please specify: [open] (2) Yes, Scope 2 emissions. Please specify: [open] (3) Yes, Scope 3 upstream emissions. Please specify: [open] (4) Yes, Scope 3 downstream emissions. Please specify: [open] (5) No, we do not measure our carbon footprint. Please specify: [open]
3	If you would like to elaborate, provide explanations, or share any comments regarding the previous question, please do so here:	Open question.	
4	Are you familiar with the CO_2e emissions of your Tier 1 suppliers? Please provide the total emissions in tonnes CO_2e if available.	Multiple-Choice (single-select) + open question.	(1) Yes, please specify: [open] (2) No. (3) Unknown.
5	What was the total amount of material supplied to DAF Trucks in 2023, expressed in metric tonnes?	Open question.	
6	Are you aware of the total greenhouse gas (GHG)	Multiple-Choice	(1) Yes, please specify in tonnes CO_2e: [open]

	emissions associated with the material you supplied to DAF Trucks in 2023?	(single-select) + Open question.	(2) No.
7	(Visible only if Q6 = Yes, please specify in tonnes CO_2e). Please indicate the specific products for which these emissions are reported:	Open question	
8	What methodology do you use to calculate your carbon footprint?	Multiple-Choice (multi-select)	(1) GHG Protocol. (2) ISO 14064. (3) Life Cycle Assessment (LCA). (4) Other, please specify: [open] (5) We do not calculate our carbon footprint.
9	Does your company report its carbon footprint in sustainability reports or other documentation?	Multiple-Choice (multi-select)	(1) Yes, in sustainability reports. (2) Yes, in regulatory filings. (3) Yes, in annual reports. (4) No, but we plan in the near future. (5) No, we do not report our carbon footprint in reports.
10	*(Visible only if Q9 = Yes, in sustainability reports).* Please add your sustainability report.	File upload	
11	Does your company have targets or goals for reducing GHG emissions related to the goods and services you provide?	Multiple-Choice (single-select)	(1) Yes, we have targets. (2) We are in the process of setting targets. (3) No, we do not have targets at this time.
12	*(Visible only if Q11 = Yes, we have targets).* Please specify the targets or goals you have set for reducing GHG emissions related to your goods and services:	Open question	
13	What challenges do you face in measuring or managing emissions from the goods and services you provide and from your suppliers?	Multiple-choice (multi-select) + open question.	(1) Complexity of emissions calculations. (2) Inconsistent reporting standards. (3) Lack of data from suppliers. (4) Lack of engaged suppliers and/or customers. (5) Lack of internal data. (6) Lack of supply chain transparency. (7) Limited resources or expertise. (8) Low priority assigned to measuring emissions internally. (9) Other, please specify: [open]

14	Does your company have a 5-year investment plan for energy efficiency improvements and cost-effective energy sources?	Multiple-Choice (single-select).	(1) Yes, we do. (2) No, we don't.
15	*(Visible only if Q14 = Yes, we do).* Please provide your 5-year investment plan for energy efficiency improvements and cost-effective energy sources:	File upload.	
16	What is the primary raw material used in the products supplied to DAF Trucks?	Open question.	
17	What is the most energy-intensive production process used for the materials supplied to DAF Trucks?	Multiple-choice question (multi-select) + open question.	(1) EAF (2) BF-BOF (3) Other:
18	What is the total energy consumption (in kWh) for the production of the materials supplied to DAF Trucks per tonne of product?	Open question.	
19	What types of energy sources are used in your production process? Please select all that apply and, if available, provide the percentage of energy used per category.	Multiple-choice question (multi-select) + open question.	(1) Coal: percentage (2) Electricity non-renewable: percentage (3) Electricity renewable: percentage (4) Natural gas: percentage (5) Oil: percentage (6) Other:
20	Do you have any additional comments, nuances, or clarifications regarding the questions in this survey?	Open question.	

Table 18: Questionnaire format European suppliers.

Closing
Thank you for taking the time to complete this survey!

Your insights will help us better understand and manage emissions in our supply chain. If you have any questions or comments, please feel free to reach out to Luc Raijmakers at luc.raijmakers1@daftrucks.com.

Appendix 4: Overview of supplier questionnaire (non-EU suppliers)

Introduction:

Thank you for taking the time to complete this survey.

DAF Trucks is gathering insights from its suppliers to better understand and manage GHG emissions in its supply chain. Your responses will be valuable to this process and will be kept confidential.

Please note that the survey will only be submitted after the last question. If a question is unclear or not relevant to your company, you may leave it blank.

If you have any questions or comments, please reach out to Luc Raijmakers at luc.raijmakers1@daftrucks.com

	Question	**Question type**	**Options**
1	Please enter the name of your company.	Open question	
2	does your company measure its annual carbon footprint? Please select all that apply and provide the greenhouse gas (GHG) emissions in tonnes of CO_2e for 2023.	Multiple-Choice (multi-select) + open question.	(1) Yes, Scope 1 emissions. Please specify: [open] (2) Yes, Scope 2 emissions. Please specify: [open] (3) Yes, Scope 3 upstream emissions. Please specify: [open] (4) Yes, Scope 3 downstream emissions. Please specify: [open] (5) No, we do not measure our carbon footprint. Please specify: [open]
3	If you would like to elaborate, provide explanations, or share any comments regarding the previous question, please do so here:	Open question.	
4	Are you familiar with the CO_2e emissions of your Tier 1 suppliers? Please provide the total emissions in tonnes CO_2e if available.	Multiple-Choice (single-select) + open question.	(1) Yes, please specify: [open] (2) No. (3) Unknown.
5	What was the total amount of material supplied to DAF Trucks in 2023, expressed in metric tonnes?	Open question.	
6	Are you aware of the total greenhouse gas (GHG) emissions associated with the material you supplied to DAF Trucks in 2023?	Multiple-Choice (single-select) + Open question.	(1) Yes, please specify in tonnes CO_2e: [open] (2) No.
7	*(Visible only if Q6 = Yes, please specify in tonnes CO_2e).*	Open question	

	Please indicate the specific products for which these emissions are reported:		
8	What methodology do you use to calculate your carbon footprint?	Multiple-Choice (multi-select)	(1) GHG Protocol. (2) ISO 14064. (3) Life Cycle Assessment (LCA). (4) Other, please specify: [open] (5) We do not calculate our carbon footprint.
9	Does your company report its carbon footprint in sustainability reports or other documentation?	Multiple-Choice (multi-select)	(1) Yes, in sustainability reports. (2) Yes, in regulatory filings. (3) Yes, in annual reports. (4) No, but we plan in the near future. (5) No, we do not report our carbon footprint in reports.
10	*(Visible only if Q9 = Yes, in sustainability reports).* Please add your sustainability report.	File upload	
11	Does your company have targets or goals for reducing GHG emissions related to the goods and services you provide?	Multiple-Choice (single-select)	(1) Yes, we have targets. (2) We are in the process of setting targets. (3) No, we do not have targets at this time.
12	*(Visible only if Q11 = Yes, we have targets).* Please specify the targets or goals you have set for reducing GHG emissions related to your goods and services:	Open question	
13	What challenges do you face in measuring or managing emissions from the goods and services you provide and from your suppliers?	Multiple-choice (multi-select) + open question.	(1) Complexity of emissions calculations. (2) Inconsistent reporting standards. (3) Lack of data from suppliers. (4) Lack of engaged suppliers and/or customers. (5) Lack of internal data. (6) Lack of supply chain transparency. (7) Limited resources or expertise. (8) Low priority assigned to measuring emissions internally. (9) Other, please specify: [open]
14	Does your company have a 5-year investment plan for energy efficiency improvements and cost-effective energy sources?	Multiple-Choice (single-select).	(1) Yes, we do. (2) No, we don’t.

15	*(Visible only if Q14 = Yes, we do).* Please provide your 5-year investment plan for energy efficiency improvmenets and cost-effective energy sources:	File upload.	
16	What is the primary raw material used in the products supplied to DAF Trucks?	Open question.	
17	What is the most energy-intensive production process used for the materials supplied to DAF Trucks?	Multiple-choice question (multi-select) + open question.	(1) EAF (2) BF-BOF (3) Other: [open]
18	What is the total energy consumption (in kWh) for the production of the materials supplied to DAF Trucks per tonne of product?	Open question.	
19	What types of energy sources are used in your production process? Please select all that apply and, if available, provide the percentage of energy used per category.	Multiple-choice question (multi-select) + open question.	(1) Coal: percentage (2) Electricity non-renewable: percentage (3) Electricity renewable: percentage (4) Natural gas: percentage (5) Oil: percentage (6) Other: [open]
20	Does your company handle its own transportation, or does it use third-party logistics (3PL) providers?	Multiple-choice question (single-select)	(1) We handle our own transportation. (2) We use third-party logistics (3PL) providers. (3) A combination of both.
21	What modes of transportation are used to deliver your products to DAF Trucks?	Multiple-choice question (multi-select)	(1) Air transport. (2) Rail transport. (3) Road transport. (4) Sea transport. (5) Unknown.
22	*(Visible only if Q21 = Road transport).* What type of fuel is used by the trucks for transportation?	Multiple-choice question (multi-select) + open question.	(1) Biodiesel. (2) CNG or LPG. (3) Diesel. (4) Electric. (5) Gasoline (6) Other, please specify: [open]
23	How are your shipments typically loaded?	Multiple-choice question (single-select)	
24	Do you share shipments with products from other companies or consolidate products from different orders to maximize the load?	Multiple-choice question (multi-select)	(1) Yes, we share shipments. (2) Yes, we consolidate orders. (3) No, we do not. (4) Unknown.

25	*(Visible only if Q21 = Air transport).* Please specify the estimated distance travelled by air (in km) per shipment to DAF Trucks:	Open question	
26	*(Visible only if Q21 = Rail Transport).* Please specify the estimated distance travelled by rail (in km) per shipment to DAF Trucks:	Open question	
27	*(Visible only if Q21 = Road Transport).* Please specify the estimated distance travelled by road (in km) per shipment to DAF Trucks:	Open question	
28	*(Visible only if Q21 = Sea Transport).* Please specify the estimated distance travelled by sea (in km) per shipment to DAF Trucks:	Open question	
29	How many shipments did your company send to DAF Trucks from January 1, 2024, to October 31, 2024?	Open question	
30	Are there any warehousing or storage points prior to the shipment reaching DAF Trucks?	Multiple-choice question (single-select)	(1) Yes. (2) No. (3) Unknown.
31	Does your company or your logistics provider implement any emission-reduction strategies, such as optimized routing, eco-driving, or low-emission vehicles?	Multiple-choice question (single-select) + open question.	(1) Yes, please elaborate: [open] (2) No. (3) Unknown.
32	Please provide an estimation of the carbon emissions associated with your transport activities to DAF Trucks, if available (in tonnes CO_2e):	Open question	
33	Do you have any additional comments, nuances, or clarifications regarding the questions in this survey?	Open question.	

Table 19: Questionnaire format non-European suppliers.

Closing:
Thank you for taking the time to complete this survey!
Your insights will help us better understand and manage emissions in our supply chain. If you have any questions or comments, please feel free to reach out to Luc Raijmakers at luc.raijmakers1@daftrucks.com.

Appendix 5: Interview protocol (semi-structured)

In the table below the semi-structured interview scheme is provided. Please not that it varies for each supplier based on their responses in the questionnaire.

Meeting structure:

1. Introduction and background of the research
2. Questions
3. Closing

1. Introduction

Thank you for taking the time to meet with me today and for completing the questionnaire. I have some additional questions based on your reply on the questionnaire. First of all, allow me to introduce myself. my name is Luc Raijmakers. I am currently studying Supply Chain Management and doing an internship at DAF Trucks. I started in September and will be finishing in January.

As part of my research at DAF, I am focusing on analysing the CO_2 emissions of our suppliers in order to gain a better understanding of Scope 3 emissions and the broader emissions across DAF's supply chain. Ultimately, the goal of this research is to help reduce the carbon footprint of DAF Trucks and the automotive industry as a whole.

The first step in reducing the carbon footprint is to understand the existing emissions, which is why I asked you to complete the questionnaire. The second step is to gain a deeper understanding of your sustainability objectives, emissions, and challenges, which is the purpose of our meeting today.

Before we begin, I would like to ask if I have your permission to record this meeting. Additionally, please note that the information you provide will remain confidential. We will not use your company name, and the data will only be shared with DAF Trucks, using your name for identification but not revealing any specific details.

Does that sound okay?

Please introduce yourself as well.

2. Questions

	Questions
1	Were there any aspects of the survey unclear to you?
2	Were there any questions you were unable to answer within the survey?
3	How important are sustainability and sustainable operations for [company name]?
4	How does current legislation influence your sustainability efforts?
5	How do your suppliers and clients influence your sustainability efforts?
6	You mention you do/do not measure scope 1,2,3 upstream and downstream emissions. Please elaborate on how you measure these emissions/why you do not measure these emissions.
7.	You mention [add number] emissions in scope 1,2, and 3. Are these numbers correct?
8	What methodology do you use to measure your emissions?
9	You are/you are not aware of the GHG emissions associated with the materials provided to DAF Trucks. How did you calculate these emissions? [OR] Why are you not aware of the total GHG emissions?
10	You mention goals to reduce GHG emissions. Can you elaborate on these goals? [OR] You mention no goals to reduce GHG emissions. Can you explain?
11	You mention [number] of challenges you encounter in measuring emissions from goods and services provided. Could you elaborate on these challenges? In what way do you encounter these challenges?
12	Please elaborate and explain your investment plan in future sustainability efforts.
13	Where do your materials come from?
14	What's the most energy-intensive production process at your company and within your supply chain?
15	You mention/you do not mention the percentage of electricity from renewable and non-renewable sources. What percentage of renewable sources is purchased, and what percentage is in-house generated?
16	Are there any additional factors influencing GHG emissions?
17	Do you have any additional comments, regarding the questions discussed in the survey or during the meeting?
(18)	Extra question when emissions appear incorrect: I noticed that the emissions are reported as [value]. Could you confirm if this is correct? Extra question when energy-usage appear incorrect: I noticed that the energy-usage is reported as [value]. Could you confirm if this is correct? Extra question: When something is unclear, extra questions are added.

Table 20: Interview questions.

3. Closing

Thank you once again for taking the time to speak with me today. Before we conclude, is there anything else you would like to add or elaborate on? If you prefer, I can also send you a summary of your responses to the questionnaire via email. If you have any further questions or would like to contact me later, please feel free to reach out through the email you received.

Appendix 6: Questionnaire and interviews information

This appendix provides an overview of the engagement process with suppliers, including timeline of their responses, interviews, and participants present during interviews. All interviews were held in English, except for Alu. Casting B Europe, Flat steel mill C Europe, and stampings B Europe, which were held in Dutch.

Table 21: Detailed information on survey replies, dates, and participants.

	Supplier	Date of reply to questionnaire	Date of interview	Participants present during interview
1	Alu. Casting A Europe	11-11-2024	05-12-2024 11:30 CET	Account director and Manager Business Development
2	Alu. Casting B Europe	22-11-2024	03-12-2024 11:00 CET	Key Account Manager and Manager Advanced Manufacturing Engineering
3	Alu. Casting C Asia	19-11-2024	25-11-2024 08:30 CET	Senior Product Development Manager and Sustainability Manager
4	Alu. Casting D Asia	25-11-2024	26-11-2024 08:30 CET	Account Manager
5	Flat steel mill A Europe	06-12-2024	06-12-2024 11:00 CET	Marketing Manager, Business Development Automotive Manager, and Technical Development Manager
6	Flat steel mill B Europe	18-11-2024	26-11-2024 12:00 CET	Sales Manager, Head of Technical Customer Service, Manager Digital Services, Business and Production Manager
7	Flat steel mill C Europe	14-11-2024	22-11-2024 09:00 CET	Key Account Manager and Marketing Manager Sustainability & Digitalisation Automotive
8	Forgings A Asia	13-11-2024	27-11-2024 14:00 CET	Head of Sales Automotive and Head of Sustainability of Thyssenkrupp Forgings
9	Forgings B Europe	12-12-2024	12-12-2024 11:00 CET	Account Manager
10	Forgings C Asia	18-11-2024	26-11-2024 09:30 CET	General Manager, Head ESG & EHS, Deputy Manager, and Company Secretary & Compliancy Officer
11	Forgings D Asia	17-11-2024	27-11 11:30 CET	Assistant Manager Business Development, Deputy Manager, Senior Account Manager, and Vice President
12	Stampings A Europe	20-11-2024	26-11-2024 14:00 CET	Sustainability, energy and environmental manager
13	Stampings B Europe	29-11-2024	05-12-2024 15:00 CET	Key Account Manager and Head of Sustainability
14	Stampings C Europe	19-11-2024	10-12-2024 09:00 CET	Lean Manager, Environmental Engineer
15	Iron casting A Europe	13-11-2024	27-11-2024 13:00 CET	Field Sales Representative, Head of Sustainability

16	Iron casting B Europe	19-11-2024	25-11-2024 15:00 CET	Customer Business Manager and Manager ESG & Compliance

Appendix 7: Coding scheme for interview data

This appendix provides an overview of the coding scheme used to analyse data collected from interviews. The coding scheme serves as a framework to systematically organise and interpret the data gathered during the interviews.

Classification	**Supplier and supply chain emissions**					
Factors	**Import duties**	**Legislation**	**Visibility and transparency**	**Cooperation suppliers**	**Government investments and support**	**Company investments**
Definition	*A tax placed on goods coming into one country from another (Cambridge University Press, n.d.)*	*A law or set of laws suggested by a government and made offical by a parliament (Cambridge University Press, n.d.)*	*Visibility: the degree to which something is seen or known about (Cambridge University Press, n.d.). Transparency: the quality of being done in an open way without secrets (Cambridge University Press, n.d.).*	*The act of working together (Cambridge University Press, n.d.).*	*Money that the government invests in something, or the activity of investing government money (Cambridge University Press, n.d.).*	*The act of putting money, effort, time into something (Cambridge University Press, n.d.).*
Data from interviews	*"The EU expects us to comply with the CBAM requirements, and these CBAM requirements are getting tightened now"*	*"We have to be carbon neutral in 2045 in Germany, and therefore we have targets and want to reduce 42% of our emissions in scope 1 and scope 2 in 2030, and 100% in 2040"*	*"We being tier one suppliers, we face challenges on both the sides to strike a balance between the clients requirements, as well as supplier clarity and the competency from the supplier side."*	*"Yes, we are cooperating with our suppliers. We are working on a sustainability programme together."*	*"When investing in a DRI and an EAF, you're talking about big investments. That's not a few hundred thousand euros. And that's also why sate support is important. Because otherwise a company would never be afford that in its life."*	*"We developed an investment plan aimed at reducing our energy consumption, which includes the implementation of a photovoltaic solar panel system and a heat recovery system."*
	"Sustainability is not of monetary importance to us, but Europe is committing to CBAM. (...) so my costs will increase, and when you are going for sustainable solutions, this impact will be less"	*"There's no real legislation in China regarding greenhouse gas emissions. It started now for some large companies, but for private companies like us, the country actually has no force requirement for that part."*	*"We have 150 plus suppliers who supply raw materials to us. So when you talk about transparency in the supply chain, we do not have a transparent supply chain. Our suppliers might not be sharing the data deliberately assuming or considering that their might be a drop in the business, and secondly not all our suppliers are ready to implement changes at their end."*	*"You know the small companies in the market are resilient, and do not share sustainability data"*	*"The original plan was that this [opening new green steel plant] should be up and running in 2026, but it's a little bit delayed due to approvals from the government"*	*"Because we outsource our logistics, we do not invest in more sustainable transport options."*
	"We should be calculating our carbon footprint for the CBAM"	*"Both international and national regulations are very, very much focused towards sustainability aspect or ESG aspects. When it comes to country level regulation (...) we have SEBI, Security Exchange Board of India, and since we cater to the internal market, the requirements relating to CSRD, are also applicable to us."*	*"We are gathering data from our suppliers. What is your value? What plans do you have to lower your CO2 figure, and so on. All suppliers cooperate, because they know the pressure is on them now."*			*"To remain operational in the Netherlands and ensure the longevity of our company, it is essential to reduce our carbon footprint."*
		"[In the future] there is no real alternative to green steel (...), and it won't be possible to import from let's say China (...) at a lower price. Because then you have the CBAM mechanism."	*"We have about three or four service providers that transport the parts from India, to the US, and Europe. That portion of emissions is not traceable for us now."*			

Table 22: Coding scheme supplier and supply chain emissions drivers.

Classification	**Supplier emissions**			
Factors	**Public pressure**	**Supplier pressure**	**Supplier size**	**Supplier practices**
Definition	*Public: people in general (Cambridge University Press, n.d.). Pressure: the act of trying to make someone do something (Cambridge University Press, n.d.).*	*Pressure: the act of trying to make someone do something (Cambridge University Press, n.d.).*	*Size: how large or small something is (Cambridge University Press, n.d.).*	*Practices: action rather than thought or ideas (Cambridge University Press, n.d.).*
Data from interviews	*"There is enough pressure from outside, from the neighbourhood and the country"*	*"Sustainability is not a topic at this moment, actually, you are the first to ask this from us."*	*"Smaller suppliers generally have less information available on their emissions, and less investments planned."*	*"there are three or four suppliers of our materials, they contribute to 85%-90% of our total emissions."*
	"Sustainability is not a topic at this moment, actually, you are the first to ask this from us."	*"We are just a supplier and have to do what our customers want from us. We have our own targets, but we have to reach the targets of our customers"*	*"we made some concepts, but they are just in plan. We have to invest many euros in projects. And that's a big problem for a small supplier in the automotive field."*	*"80% of our emissions come from the materials supplied to us."*
		"We being tier one suppliers for OEM's,	*"Not all our supplies are willing to do that*	*"More than 60% of our emissions are within scope*

Table 23: Coding scheme supplier emissions drivers.

Classification	Supply chain emissions	
Factors	**Geographical location**	**Transport optimisation**
Definition	Location: position (Cambridge University Press, n.d.).	Optimisation: to make something as good as possible (Cambridge University Press, n.d.).
Data from interviews	"Our shipments travel from Sweden to Maastricht by train and then to Eindhoven by truck. However, in comparison to our production emissions, these transportation emissions are negligible."	"Our shipments travel from Sweden to Maastricht by train and then to Eindhoven by truck."
	"See here [India], there is not electric transportation within the truck or bus segment. (...)	"Our shipments are transported from IJmuiden to Maastricht and subsequently returned to Eindhoven."

Table 24: Coding scheme supply chain emissions drivers.

Appendix 8: Archival data cleaning

For the data cleaning process, the following document was used: 'Transporeon orders 2024 YTD (Q3)'.

Number of rows	68,022

Table 25: Number of rows archival data transport.

The first step in the cleaning process, was deleting all the suppliers not included in this research. This was done by selecting only the suppliers included in the research by filtering the 'Loading station – code' on the following companies. This resulted in a total of 5,412 rows. Transport data of 'Flat steel mill A Europe' was not available and was gathered via the questionnaire. Transport data of 'Flat steel mill B Europe' was unreliable, due to missing data, and is therefore not included in the further analysis, but more reliable data on transport emissions is gathered via the questionnaire, deep-dive and the meeting.

Supplier name	Loading station - code
Alu. Casting A Europe	83867 - 'Alu. Casting A Europe' (G11311)
	83867 - 'Alu. Casting A Europe'
	JDR - 83867 - 'Alu. Casting A Europe' (G11311)
Alu. Casting B Europe	99670 - 'Alu. Casting B Europe'
Alu. Casting C Asia	88733 - 'Alu. Casting C Asia'
	99522 - 'Alu. Casting C Asia'
Alu. Casting D Asia	86605 - 'Alu Casting D Asia'
Forgings A Asia	89093 - 'Forgings A Asia'
Forgings B Europe	75040 - 'Forgings B Europe'
	89989 - 'Forgings B Europe'
Forgings C Asia	89630 - 'Forgings C Europe'
Forgings D Asia	89223 - 'Forgings D Asia'
Iron Casting A Europe	88340 - 'Iron Casting A Europe' 1
	88340 - 'Iron Casting A Europe' 2
	88340 - 'Iron Casting A Europe'
	XP 88340 - 'Iron Casting A Europe'
	98644 - 'Iron Casting A Europe' (88340)
Iron Casting B Europe	78560 - 'Iron Casting B Europe' (j21566)
	JDR - 78560 - 'Iron Casting B Europe' (j21566)
Stampings A Europe	86544 - 'Stampings A Europe'
	86544 - Stampings A Europe
	87595 - Stampings A Europe
Stampings B Europe	14403 - 'Stampings B Europe'
Stampings C Europe	80375 - 'Stampings C Europe'

80372 - 'Stampings C Europe'

Please note: The loading-station codes are anonymised.

Table 26: Supplier names and Loading station - codes.

Following, only supplies to DAF Trucks Westerlo or DAF Trucks Eindhoven were included. This was done by filtering the row ‘Shipment end location company’. This resulted in a total of 4,856 rows.

Shipment end location company - filter
DAF TRUCKS EINDHOVEN NV
DAF TRUCKS WESTERLO NV
PACCAR ENGINE COMPANY
PACCAR PARTS EINDHOVEN

Table 27: Filtering shipment end location.

All shipments exceeding 40 tons were reviewed, as weights above this threshold are not feasible for a single shipment. 29 Entries corresponding with Loading Station - Code: ‘89223 - BHARAT FORGE GEVELSBERG’ and ‘89223’, with weights ranging between ’23,515,500.00’ and ’23,500,000.00’, were corrected to ’23,500.00’, since these figures contained errors in the document. Additionally, three entries with weights ranging from 1,540,000 kg and 170,000 kg were removed, as these weights were considered and no accurate weight data could be located.

Tour number	Correction/Change made
903885	Correction to 23,500.00 kg
922621	Correction to 23,500.00 kg
922723	Correction to 23,500.00 kg
914142	Correction to 23,500.00 kg
914143	Correction to 23,500.00 kg
943016	Correction to 23,500.00 kg
947372	Correction to 23,500.00 kg
963474	Correction to 23,500.00 kg
953687	Correction to 23,500.00 kg
963473	Correction to 23,500.00 kg
961594	Correction to 23,500.00 kg
961593	Correction to 23,500.00 kg

924859	Correction to 23,500.00 kg
924860	Correction to 23,500.00 kg
904682	Correction to 23,500.00 kg
914141	Correction to 23,500.00 kg
924855	Correction to 23,500.00 kg
924856	Correction to 23,500.00 kg
924858	Correction to 23,500.00 kg
929109	Correction to 23,500.00 kg
943015	Correction to 23,500.00 kg
947373	Correction to 23,500.00 kg
947374	Correction to 23,500.00 kg
947375	Correction to 23,500.00 kg
961589	Correction to 23,500.00 kg
961590	Correction to 23,500.00 kg
961591	Correction to 23,500.00 kg
961592	Correction to 23,500.00 kg
963472	Correction to 23,500.00 kg
953775	Deletion of row
909124	Deletion of row
904988	Deletion of row

Table 28: Reviewed 'Tour number' codes and corrective action.

The cleaned document consisted of a total of 4,852 rows.

Number of rows	4,852

Table 29: Number of rows after data cleaning.

Subsequently, the distance between the shipments was calculated for all transports by determining the shipment start and end location, utilising the shortest available routes via Google Maps, on December 3, 2024. For air transport, the distance was calculated using the flight distance tool provided by nl.distance.to.

In appendix 8, the number of transports per supplier, and corresponding emissions are presented.

Appendix 9: CO_2e emissions breakdown by supplier and scope

The table below presents detailed information on the total GHG emissions, expressed in CO_2e, for the suppliers analysed. However, due to incomplete data provided by some suppliers, certain information is not available for all suppliers. A comprehensive explanation of total emissions and their data sources is provided in the text following the table.

Company	Total product delivered to DAF Trucks (tonnes 2023)	CO_2e emissions from production (tonnes)	CO_2e emissions from transport (tonnes)	CO_2e emissions per kg of end product (kg)	Scope 1 emissions (%)	Scope 2 emissions (%)	Scope 3 upstream emissions (%)	Scope 3 downstream emissions (%)
Alu. Casting A Europe	293	1,430	56	5.1	8.5%	5.8%	85.7%	
Alu. Casting B Europe	1,641	1,428	4	7.6	18.7%	14.6%	66.7%	
Alu. Casting C Asia	289		64					
Alu. Casting D Asia	790	1,300	51	1.7	19.0%	81.0%		
Flat steel mill A Europe	22,253	45,173	1018	2.1	99.9%	0.0%	0.1%	
Flat steel mill B Europe	6,299	14,901		2.4	85.0%	0.0%	15.0%	
Flat steel mill C Europe	13,411	29,791	212	2.2	74.3%	0.3%	20.9%	4.6%
Forgings A Asia	3,045	6,700	520	2.2	74.0%	26.0%		
Forgings B Europe	3,360							
Forgings C Asia	4,704	5,594	559	1.3	17.0%	83.0%		
Forgings D Asia	4,959	14,827	632	3.1	10.2%	20.5%	59.6%	9.7%
Stampings A Europe	12,000	29,880	723	2.6	3.7%	2.7%	93.6%	
Stampings B Europe			86	2.3	36.9%	63.1%		
Stampings C Europe	10,000	30,000	371	3.0				
Iron casting A Europe	42,413	68,500	661	1.6	39.5%	16.7%	43.8%	0.0%
Iron casting B Europe	3,241		82		48.5%	51.5%		

Table 30: CO_2e emissions supplier and supply chain.

Note: Yellow-marked cells indicate that only scope 1, and scope 2 emissions were included in the calculation. Green-marked cells indicate that scope 1, scope 2, and scope 3 emissions were included in the calculation.

Total product delivered to DAF Trucks

The data on total product delivered to DAF Trucks (year: 2023) is primarily derived from questionnaire responses. Exceptions include ‘Forgings A Europe’, for which the total product delivered is calculated based on total emissions, and emission per kg of end product, and ‘Stampings B Europe’, for which no data was provided.

Emissions from production

The sources of data from total CO_2e emissions from production to DAF Trucks, are summarised below.

Company name	Source(s) of data
Alu. Casting A Europe	Meetings (provided document)
Alu. Casting B Europe	Questionnaire
Alu. Casting C Asia	Not provided
Alu. Casting D Asia	Questionnaire
Flat steel mill A Europe	Questionnaire
Flat steel mill B Europe	Questionnaire
Flat steel mill C Europe	Questionnaire
Forgings A Asia	Questionnaire
Forgings B Europe	Not provided
Forgings C Asia	Year report + material provided to DAF Trucks
Forgings D Asia	Questionnaire
Stampings A Europe	Questionnaire
Stampings B Europe	Meetings (additional document)
Stampings C Europe	Meetings (additional document)
Iron casting A Europe	Questionnaire
Iron casting B Europe	Not provided

Table 31: Data sources of emissions from production.

Emissions from transport

The sources of data from total CO_2e emissions from transport to DAF Trucks, are summarised below.

Company name	Source(s) of data
Alu. Casting A Europe	Archival data
Alu. Casting B Europe	Archival data
Alu. Casting C Asia	Archival data + Questionnaire
Alu. Casting D Asia	Archival data + Questionnaire
Flat steel mill A Europe	Questionnaire + Meeting
Flat steel mill B Europe	Archival data
Flat steel mill C Europe	Meeting
Forgings A Asia	Archival data
Forgings B Europe	Archival data
Forgings C Asia	Archival data + Questionnaire
Forgings D Asia	Archival data + Questionnaire
Stampings A Europe	Archival data
Stampings B Europe	Archival data
Stampings C Europe	Archival data
Iron casting A Europe	Archival data
Iron casting B Europe	Archival data

Table 32: Data sources of emissions from transport.

Percentage of emissions per scope

The sources of data for the percentage of emissions by scope 1, scope 2, and scope 3 are summarised below. It is clear that not all companies provided measurements for all scopes. Furthermore, due to the confidentiality of certain data, percentages were utilised instead of exact numbers.

Company name	Source(s) of data
Alu. Casting A Europe	Document provided during meeting
Alu. Casting B Europe	Document provided during meeting
Alu. Casting C Asia	Unknown

Alu. Casting D Asia	Questionnaire
Flat steel mill A Europe	Questionnaire (later correct by year report)
Flat steel mill B Europe	Questionnaire
Flat steel mill C Europe	Questionnaire
Forgings A Asia	Meeting (inconsistent with questionnaire)
Forgings B Europe	Unknown
Forgings C Asia	Questionnaire
Forgings D Asia	Questionnaire
Stampings A Europe	Questionnaire
Stampings B Europe	Questionnaire
Stampings C Europe	Document provided during meeting
Iron casting A Europe	Questionnaire
Iron casting B Europe	Questionnaire

Table 33: Data sources for calculation of emissions per scope.

Emissions per kg of end product

The CO_2e emissions per kg of end product were calculated using the following formula:

$$CO_2e\ per\ kg\ of\ end\ product\ (in\ kg) = \frac{CO_2e\ production\ of\ material\ to\ DAF\ Trucks\ (in\ kg) +\ CO_2e\ transport\ to\ DAF\ Trucks}{Total\ product\ delivered\ to\ DAF\ Trucks\ (kg)}$$

This calculation was applied to the following companies: ‘Alu. casting A Europe’, ‘Alu. Casting D Asia’, ‘Forgings C Asia’, ‘Forgings D Asia’, ‘Stampings A Europe’, ‘Iron casting A Europe’, and ‘Flat steel mill B Europe’.

For the other companies: ‘Alu. Casting B Europe’, ‘Flat steel mill A Europe’, ‘Flat steel mill B Europe’, ‘Forgings A Asia’, ‘Stampings B Europe’, and ‘Stampings C Europe’ emissions per kg of end product were directly provided by the companies.

It is important to note that not all companies comprehensively measure their scope 1, scope 2, and scope 3 emissions. Consequently, the data are not completely comparable across all suppliers.

Appendix 10: Overview of measured emissions by suppliers

The table below presents a detailed overview of the scopes measured by suppliers across scope 1, scope 2, and scope 3. The table highlights the extent to which different suppliers measure their emissions. As seen, not all suppliers measure emissions for each scope, indicating varying level of maturity in their carbon accounting practices.

Company	**Scopes**																
	Scope 1	Scope 2	Scope 3 cat 1	Scope 3 cat 2	Scope 3 cat 3	Scope 3 cat 4	Scope 3 cat 5	Scope 3 cat 6	Scope 3 cat 7	Scope 3 cat 8	Scope 3 cat 9	Scope 3 cat 10	Scope 3 cat 11	Scope 3 cat 12	Scope 3 cat 13	Scope 3 cat 14	Scope 3 cat 15
Alu. Casting A Europe	X	X	X			X											
Alu. Casting B Europe	X	X	X	X	X	X	X	X	X								
Alu. Casting C Asia																	
Alu. Casting D Asia	X	X															
Flat steel mill A Europe	X	X	X	X	X	X	X	X	X	X							
Flat steel mill B Europe	X	X			X												
Flat steel mill C Europe	X	X	X	X	X	X	X	X	X		X	X		X			
Forgings A Asia	X	X															
Forgings B Europe	X	X															
Forgings C Asia	X	X															
Forgings D Asia	X	X	X	X	X	X	X	X	X	X	X						
Stampings A Europe	X	X	X	X	X	X	X	X	X								
Stampings B Europe	X	X															
Stampings C Europe	X	X	X		X	X	X	X			X						
Iron casting A Europe	X	X															
Iron casting B Europe	X	X															

Table 34: Overview of emission categories measured by suppliers.

Appendix 11: Supplier investments and sustainability objectives

The table below presents an overview of the investments and sustainability objectives of the analysed suppliers, along with their main material usage.

Company	Investments	Material	Objectives
Alu. Casting A Europe	Photovoltaic panel system Heat recovery from melting furnace	Combination between secondary and primary aluminium	100% Energy neutral from 1st quarter 2025.
Alu. Casting B Europe	Sustainability team + complete visibility of Supply Chain	Combination between secondary and primary aluminium	Green as soon as possible.
Alu. Casting C Asia	No current investments	30% secondary aluminium	No goals
Alu. Casting D Asia	Solar panels LPG instead of oil Third party for renewable energy instead of non-renewable energy (with Tidal power)	60% recycled (high pressure die casting), 40% non-recycled (gravity die casting)	50% reduction by 2025, and 100% reduction by 2039 in scope 1, 2, 3.
Flat steel mill A Europe	HYBRIT Technology SSAB ZeroTM (recycled steel) SSAB FossilTM-Free (sponge iron) Hydrogen Storage	Raw material and scrap-based	Fossil free by 2030 (scope 1 and scope 2) (personal communication)
Flat steel mill B Europe	DRI-EAF Plants Green Hydrogen Green Steel (Zeremis)	Raw material and scrap-based	40% reduction in scope 1 + 2 in 2030. (Personal communication)
Flat steel mill C Europe	DRI-EAF Plants Bluemint Steel ZM Ecoprotect Solar Green Hydrogen	Raw material and scrap-based	Carbon neutral in 2030 (scope 1 and scope 2) (Thyssenkrupp, 2023).
Forgings A Asia	Renewable energy	Steel	100% Carbon Neutral by 2038 (Musashi Seimitsu Industry, 2023).
Forgings B Europe	Renewable energy through solar plants	Round steel bar	100% reduction in scope 1 and scope 2 emissions by 2033.
Forgings C Asia	No specific investment plan	60-70% recycled steel	54.6% reduction scope 1, 2 and 3 by 2033.
Forgings D Asia	No specific investment plan	0% recycled steel	
Stampings A Europe	Saving energy through investments in factory Switch to green energy (partly in-house through solar panels)	100% recycled steel	100% reduction in scope 1 and scope 2 emissions by 2035 25% reduction in scope 3 emissions by 2035
Stampings B Europe	100% Green energy	80% recycled steel	
Stampings C Europe	Photovoltaic system Substitution of cupola furnace II by electric melting Carbon capture cupola I Heat capture	100% scrap steel	CO_2 neutral by 2045 in scope 1,2,3 100% renewable energy
Iron casting A Europe	Solar panels	80% scrap steel 20% cast iron	50% reduction by 2030

Table 35: Investments and sustainability goals.

Appendix 12: Breakdown of transport emissions

The following section provides a detailed analysis of the calculated transport emissions.

Supplier	Total shipments	Distance (km)	Modality	CO2 emission per tonne product (kg)	Average weight (tonnes)	Total CO2 emission (in kg) until 31-10-2024	Extrapolated to whole 2024
Alu. Casting A Europe	63	1015	Diesel Truck	0.057	13	46,286	55,543
Alu. Casting B Europe	173	47.8	Diesel Truck	0.057	7	3,070	3,684
Alu. Casting C Asia	42	9.7	Diesel Truck	0.057	8	189	226
	42	12000	Boat	0.013	8	53,189	63,827
Alu. Casting D Asia	44	460.2	Diesel Truck	0.057	7	8,614	10,336
	44	7900	Boat	0.013	7	33,724	40,469
Flat steel mill A Europe	500	1525	Train	0.022	45	746,588	895,906
	500	80	Diesel Truck	0.057	45	101,474	121,768
Flat steel mill C Europe	450	231	Diesel Truck	0.057	30	176,583	211,899
	450	82	Diesel Truck	0.057	30	62,683	75,220
Forgings A Asia	142	9.7	Diesel Truck	0.057	18	1,443	1,731
	142	12000	Boat	0.013	18	407,043	488,452
	6	8837	Plane	0.602	1	25,025	30,030
	6	130	Diesel Truck	0.057	1	35	42
Forgings B Europe	198	302	Diesel Truck	0.057	15	49,612	59,535
Forgings C Asia	217	306	Diesel Truck	0.057	9	35,684	42,821
	217	16185.7	Boat	0.013	9	430,480	516,576
Forgings D Asia	105	201	Diesel Truck	0.057	27	32,781	39,338
	105	13286	Boat	0.013	27	494,189	593,027
Stampings A Europe	1424	340.6	Diesel Truck	0.057	22	602,292	722,750
Stampings B Europe	462	145	Diesel Truck	0.057	19	71,653	85,983
Stampings C Europe	567	505	Diesel Truck	0.057	19	309,105	370,926
Iron casting A Europe	1192	353	Diesel Truck	0.057	23	551,062	661,274
Iron casting B Europe	217	337.4	Diesel Truck	0.057	16	68,008	81,610

Table 36: Detailed transport emissions breakdown.

Supplier	Average CO_2e emission per shipment (kg)	Total CO_2e emission (in tonnes) until 31-10-2024
Alu. Casting A Europe	735	46
Alu. Casting B Europe	18	3
Alu. Casting C Asia	1271	53
Alu. Casting D Asia	962	42
Flat steel mill A Europe	1696	848
Flat steel mill C Europe	392	177
Forgings A Asia	2929	434
Forgings B Europe	251	50
Forgings C Asia	2148	466
Forgings D Asia	5019	527
Stampings A Europe	423	602
Stampings B Europe	155	72
Stampings C Europe	545	309
Iron casting A Europe	462	551
Iron casting B Europe	313	68

Table 37: Average CO_2e emissions per transport in kg.

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Appendix 13: Comparison of supplier and supply chain emissions

The table below displays the percentage of emissions at supplier level, compared to transportation.

Supplier	% CO_2e in production	% CO_2e in transportation.
Alu. Casting A Europe	96.3%	3.7%
Alu. Casting B Europe	99.7%	0.3%
Alu. Casting D Asia	96.2%	3.8%
Flat steel mill A Europe	97.8%	2.2%
Flat steel mill C Europe	99.3%	0.7%
Forgings A Asia	92.8%	7.2%
Forgings C Asia	90.9%	9.1%
Forgings D Asia	95.9%	4.1%
Stampings A Europe	97.6%	2.4%
Iron casting A Europe	99.0%	1.0%
Average	97%	3%

Table 38: Percentage of emissions at supplier level, and at transportation level.

The table below displays the average CO_2e emissions for both EU and non-EU suppliers. As expected, non-EU suppliers generally exhibit higher CO_2e emissions in transport.

CO_2e emissions within:	Non-EU suppliers	EU suppliers
Production	98%	94%
Transportation	2%	6%

Table 39: Comparison of CO_2e emissions between EU and non-EU suppliers, within production and transportation.

Lastly, in the table below the average CO_2e emissions within the scope 3 of suppliers are given. As seen, on average the highest emissions are within scope 3.

Company name	Total percentage scope 3 emissions
Alu. Casting A Europe	85.7%
Alu. Casting B Europe	66.7%
Flat steel mill A Europe	0.1%
Flat steel mill B Europe	15.0%
Flat steel mill C Europe	25.5%
Forgings D Asia	69.3%
Stampings A Europe	93.6%
Iron casting A Europe	43.8%

Table 40: Percentage of scope 3 emissions per supplier.