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Sustainability in the Heavy Truck Industry

A Competitive Benchmarking Study of Sustainability Strategies and Technologies

Bachelor's Thesis

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Cover page image: A Volvo Group truck driving on a desert highway. Image source: Volvo Group.

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Abstract

The truck industry is undergoing a sustainability transition driven by regulatory pressure, technological development, and changing market conditions. At the same time, geopolitical uncertainty and evolving regulations create challenges for long-term strategic planning and technology investment. Against this background, the study aims to analyse how leading actors in the truck industry integrate sustainability goals and which technological and operational approaches are applied, in order to evaluate Volvo Group's position relative to its competitors. The study also examines how future geopolitical developments and regulatory changes may influence the industry's continued evolution. The research is based on benchmarking of leading companies, a weighted scoring model, and scenario planning to provide recommendations for Volvo Group regarding future strategic directions. The results show that sustainability has become a strategically embedded core issue across all studied companies, with regulatory requirements remaining the main driving force. The analysis indicates that Scope 3 emissions represent the most significant source of climate impact, leading OEMs to increasingly focus on alternative powertrains, predictive maintenance, and optimisation of existing diesel-based solutions. At the same time, circularity and material efficiency emerge as strategically important but still underdeveloped areas. Scenario planning highlights that the interaction between regulatory frameworks and geopolitical stability strongly influences technology choices, investment decisions, and supply chain configurations. Stricter regulation accelerates electrification, while geopolitical uncertainty increases the need for resilience and flexibility. For Volvo Group, key development areas include service-based offerings, improved maintenance solutions, increased modularisation of components, and reduced energy consumption and waste in painting processes. Overall, the study shows that the transformation of the truck industry is gradual and uncertain, where strategic execution capabilities and external structural factors jointly shape future development.

Keywords: sustainability, heavy truck industry, benchmarking, Scope 3 emissions, decarbonisation, electrification, scenario planning, circular economy

Sammandrag

Lastbilsindustrin genomgår en hållbarhetsomställning driven av regulatoriska krav, teknologisk utveckling och förändrade marknadsförutsättningar. Samtidigt skapar geopolitisk osäkerhet och föränderliga regelverk utmaningar för långsiktig strategisk planering och teknologiska investeringar. Mot denna bakgrund syftar studien till att analysera hur ledande aktörer inom lastbilsindustrin integrerar hållbarhetsmål och vilka teknologiska samt operativa arbetssätt som används för att utvärdera Volvo Groups position i relation till sina konkurrenter. Studien undersöker även hur geopolitiska och regulatoriska förändringar kan påverka industrins fortsatta utveckling. Studien bygger på benchmarking av ledande aktörer, en viktad poängmodell och scenarioplanering för att ta fram rekommendationer till Volvo Group kring framtida strategiska vägval. Resultaten visar att hållbarhet har blivit en strategiskt integrerad kärnfråga i samtliga studerade företag, där regulatoriska krav fortsatt utgör den främsta drivkraften. Analysen visar även att Scope 3-utsläpp är den mest betydande klimatpåverkande faktorn, vilket driver ett ökat fokus på prediktivt underhåll, alternativa drivlinor, och optimering av befintliga dieselbaserade lösningar. Samtidigt framträder cirkularitet och materialeffektivitet som strategiskt viktiga men fortfarande underutvecklade områden. Scenarioplaneringen visar vidare att samspelet mellan regulatoriska ramverk och geopolitisk stabilitet i hög grad påverkar teknologival, investeringsbeslut och försörjningskedjor. Starkare reglering driver elektrifiering, medan geopolitisk osäkerhet ökar behovet av resiliens och flexibilitet. För Volvo Group identifieras särskilt utvecklingsområden inom tjänstebaserade erbjudanden, förbättrat underhåll, ökad modularisering av komponenter samt minskad energianvändning och avfall i lackeringsprocesser. Sammantaget visar studien att omställningen inom lastbilsindustrin är gradvis och präglas av osäkerhet, där strategisk genomförandeförmåga och externa strukturella faktorer tillsammans formar industrins framtida utveckling.

Preface

This report is the result of a bachelor's thesis carried out during the spring of year 2026 at the Department of Mechanics and Maritime Sciences at Chalmers University of Technology, on behalf of Volvo Group North America and in collaboration with a capstone project at Pennsylvania State University, USA. The work was conducted by students from the programmes Global Systems Engineering, Industrial Design Engineering, Mechanical Engineering and Industrial Engineering and Management.

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E. Adolfsson, S. Hagström, T. Hellström, H. Lindström, E. Sirsjö, K. Westfeldt, Gothenburg, May, 2026

Contents

Conceptual Definitions

Alternative Fuel Vehicle (AFV):
A vehicle powered by non-petroleum sources such as electricity, hydrogen, natural gas, or biofuels.

Battery Electric Vehicle (BEV):
A vehicle powered entirely by electricity.

Fuel Cell Vehicle (FCV):
A vehicle that generates electricity using hydrogen.

Internal Combustion Engine (ICE):
An engine that generates mechanical power by burning fuel inside the engine, typically diesel.

Fresh Water Consumption:
The volume of freshwater used by the company to manufacture one vehicle.

Non-Recycled Hazardous Waste:
Hazardous waste that is not recycled and requires controlled disposal due to environmental or health risks.

Non-Recycled Non-Hazardous Waste:
Non-hazardous waste that is not reused or recycled and is instead disposed of.

Original Equipment Manufacturer (OEM):
A company that produces vehicles or components under its own brand.

Particulate Matter in Tire Wear:
Small particles released from tire wear during vehicle use.

Renewable Energy Use:
The share of energy consumed by the company that originates from renewable sources.

Scope 1 emissions:
Direct emissions originating from sources that are owned or controlled by the company.

Scope 2 emissions:
Indirect emissions from the energy the company purchases and uses.

Scope 3 emissions:
Other indirect emissions that occur in the value chain, including upstream emissions from purchased goods and downstream emissions from the use phase.

Substances of Concern:
Chemical substances that may pose risks to human health or the environment and are therefore subject to regulation or monitoring.

Total Cost of Ownership (TCO):
The total cost of a product over its lifetime.

Total Energy Consumption:
The amount of energy used to manufacture one vehicle.

Well-to-Wheel:
An assessment perspective that covers the stages from energy extraction to the use of that energy in the vehicle.

1 Introduction

This chapter introduces the background and motivation for the study and presents the purpose and objectives of the report. It then outlines the main problem areas related to sustainability in the heavy truck industry including strategic integration and future regulatory and geopolitical uncertainty. Finally the chapter defines the scope and delimitations of the study to clarify the focus of the analysis.

1.1 Background

The transport sector is undergoing a fundamental transformation driven by climate change, resource constraints and increasing demands for sustainable solutions from customers, regulators and society. Freight transport plays a critical role in global economic activity, but it is also associated with significant environmental impact. According to the International Renewable Energy Agency [1], heavy trucking was responsible for 5 % of the global emissions in 2023. At the same time, the demand for freight transport is expected to double by 2050, driven by an increase of global trade [2]. This combination of rising transport demand and the need to reduce emissions, positions companies in the heavy truck sector as important actors in the transition towards a more sustainable transport system.

In response to these challenges, governments across the world are introducing stricter regulations aimed at reducing greenhouse gas emissions and promoting the adoption of sustainable technologies. The Environmental Protection Agency [3] has introduced new standards with the aim of reducing greenhouse gas emissions from heavy trucks, targeting model years starting from 2027. The regulations are technology neutral in their design, but in practice they encourage the adoption of new powertrain technologies such as electrification, hydrogen-based solutions and other low emission alternatives. At the same time, regulatory requirements differ between markets and between federal and state levels in the US, increasing the complexity for heavy trucking companies operating in North America [4]. This fragmented landscape increases the need to understand and compare how companies integrate sustainability into manufacturing, product development and long-term technology strategies. Differences in approach may affect regulatory compliance and competitive positioning.

Heavy truck companies are investing heavily in R&D to meet these new standards and strengthen their market position by developing and promoting new environmentally friendly solutions. Volvo Group reports R&D expenditures of approximately 45 billion SEK in 2024, with a significant focus on developing solutions aimed at reducing life cycle greenhouse gas emissions [5]. However, the fierce competition to meet new standards has given rise to concerns regarding greenwashing. While heavy truck companies market their green initiatives, the extent of actual sustainability efforts can be difficult to assess. For instance the Natural Resources Defense Council [6] highlights a discrepancy where certain heavy truck companies lobby against the introduction of stricter climate policies in the United States, while simultaneously promoting accomplishments in emission reduction [6]. This contrast between communicated initiatives and actual behaviour underscores the need for transparent and measurable evaluation of sustainability performance.

1.2 Purpose

The purpose of this study is to analyse how selected heavy truck manufacturers integrate sustainability goals into their strategies and operations. By benchmarking Volvo Group against key competitors, the study aims to identify best practices and areas for improvement that can support recommendations for strengthening Volvo Group's sustainability performance. The study further examines how regulatory and geopolitical developments may shape future conditions in the heavy truck market.

1.2.1 Objectives

To clearly define the aims of this thesis, the following objectives have been formulated. These objectives served as the basis for the development of the research questions and were used to guide the direction and scope of the study.

- Develop an understanding of how sustainability goals are integrated into heavy truck companies.
- Enable objective comparison of sustainability performance among truck manufacturers.
- Facilitate prioritisation of solutions that deliver real climate and business impact.
- Propose new practices for Volvo Group to implement in heavy truck production to improve sustainability performance.
- Develop an understanding of how the future heavy truck market may evolve in response to regulatory developments and the geopolitical environment.

1.3 Problem Analysis

This section examines key challenges related to sustainability in the heavy truck industry. The analysis focuses on how sustainability goals are integrated into corporate strategies, which technological solutions are used to achieve these goals and how evolving regulatory and market requirements influence companies decisions and future development.

1.3.1 Integration of Sustainability Goals Among Heavy Truck Companies

In recent years, sustainability-related goals such as decarbonisation, circularity and lifecycle perspectives have assumed an increasingly central role in decision-making among companies operating in the heavy truck industry and are partly driven by increasing regulatory pressure [7]. These goals are no longer treated solely as regulatory requirements or communication issues, but are increasingly integrated into corporate management, product development and economic decision-making models.

Sustainability goals are increasingly shaping strategic decision-making and reshaping how product development is organised, which technologies are prioritised and how the long-term profitability of investments is evaluated. This is exemplified by Volvo Group's stated position that the transition to fossil-free and sustainable transport is at the heart of everything they do [8]. As a result traditional economic calculations are complemented by lifecycle considerations, emission-related risks and anticipated regulatory requirements. Sustainability has thus become a factor that directly affects competitiveness rather than parallel or peripheral concern.

Against this background, it is relevant to analyse how different heavy truck companies adapt their internal governance structures and decision-making processes to manage increasing sustainability demands.

In relation to this, the following research questions are formulated:

- Which sustainability goals are integrated into product development and business models?
- Which sustainability goals are the most critical for achieving significant impact in the heavy truck industry?

These research questions are addressed in section 4.2, where the results and analysis of the integration of sustainability goals in product development and business models are presented.

1.3.2 Technological Solutions for Achieving Sustainability Goals

The heavy truck industry is characterized by high technical complexity, extensive value chains and large capital investments. Previous research on the industry shows that this complexity creates challenges for implementing sustainable supply chain practices [9]. As sustainability requirements become more important, partly driven by stricter CO_2 standards for heavy trucks, manufacturers need to identify which technologies, processes and operational practices can generate the greatest environmental improvements [10], [11]. These improvements may occur in several parts of the value chain, including vehicle use, manufacturing operations and waste management. This is consistent with the GHG Protocol, which distinguishes between direct emissions from company operations, indirect emissions from purchased energy and other indirect emissions occurring across the value chain [12].

Different companies in the heavy truck industry approach the sustainability transition in different ways, depending on their markets, product portfolios, production systems and strategic priorities. The transition toward zero-emission trucks affects several areas of the industry, including vehicle technology, charging infrastructure, digital solutions, services and customer operations [13]. This shows that sustainability improvements cannot be understood only through one technology or one part of the value chain. Instead, there is a need to compare how different manufacturers work with sustainability in practice in order to identify effective processes, systems and best practices that may support further environmental improvements.

This report therefore analyses selected sustainability-related systems and processes used by heavy truck manufacturers. By comparing the approaches of different companies, the study identifies best practices that appear to have strong potential for reducing environmental impact. These practices are then compared with Volvo Group's current work in order to identify gaps and formulate recommendations for improvement.

In relation to this, the following research questions are formulated:

- Which sustainability-related technologies, systems and operational practices can be identified among heavy truck manufacturers?
- Which technological or operational improvements should Volvo Group prioritise to strengthen its sustainability performance?

These research questions are addressed in section 4.4, where the results and analysis of the technological solutions for sustainability improvement are presented.

1.3.3 Future Geopolitical and Regulatory Uncertainty

The heavy truck industry is increasingly shaped by a combination of geopolitical instability and evolving sustainability regulations. These external conditions create a complex and uncertain environment, where long-term strategic planning becomes more challenging for industry actors [13].

From a geopolitical perspective, it has become increasingly difficult for companies to plan and manage their value chains over the long term. Global trade is increasingly characterized by rising tensions, trade barriers and tariffs, which affect both cost structures and supply chain reliability [14]. In particular, the industry's dependency on China for critical components such as batteries and raw materials introduces significant risk. A deterioration in geopolitical relations may disrupt access to these inputs, increase costs and force companies to reconfigure their supply chains [15].

At the same time, sustainability-related regulations are evolving and often inconsistent across regions and over time [13]. This variability complicates long-term investment decisions, particularly in capital-intensive areas such as electrification and infrastructure development. Companies cannot rely on stable policy incentives to support these investments, which increases financial risk and may reduce expected profitability. In addition, uncertain regulatory conditions can slow down the expansion of necessary infrastructure, further delaying the transition toward sustainable transport solutions [15].

Regulatory differences also influence competitive dynamics. Chinese manufacturers often benefit from strong policy support, including subsidies and industrial policy incentives, which accelerate technological development and market adoption [15]. In contrast, companies in North America may face less consistent support, creating an uneven competitive landscape where Western firms risk falling behind in both cost efficiency and innovation.

Taken together, these dynamics create a dual strategic challenge. Companies must navigate increasing pressure to transition toward sustainable solutions, while simultaneously managing uncertainty related to both regulatory frameworks and geopolitical developments. This makes it difficult to determine which technologies to prioritise, how to structure supply chains, and how to allocate resources over time [13], [14].

In relation to this, the following research questions are formulated:

- How can different combinations of regulatory support for sustainability and geopolitical developments shape future conditions in the heavy truck industry?
- How do these alternative future scenarios influence sustainability strategies, technology choices and supply chain configurations?

These research questions are addressed in section 4.5, where the results and analysis of the impact of geopolitics and sustainability regulations on future strategic development are presented.

1.4 Delimitations

The benchmark covers selected leading global heavy truck Original Equipment Manufacturers (OEMs), including Volvo Group, PACCAR, Daimler Truck, Traton Group and Isuzu Trucks. Within Traton Group, the analysis includes MAN, Scania, and International as sub-brands.

The benchmark focuses on environmental sustainability and does not include an assessment of social or economic sustainability. A full life cycle assessment is not conducted, although selected life cycle related metrics such as Scope 3 emissions and end-of-life consideration are included.

The benchmark is limited by the availability and comparability of publicly reported data. Since companies use different reporting methods, baselines and levels of detail, the benchmark results should be seen as an indication rather than a definitive assessment.

The recommendations provided to Volvo Group are based on the benchmarking results and qualitative analysis. However, implementation costs and financial feasibility are outside the scope of this study.

1.5 Structure of the report

This chapter has introduced the background and purpose of the study, together with the study's objectives, problem analysis, research questions, and delimitations. The remaining part of this report is structured as follows. Chapter 2 presents the theoretical background and key concepts relevant to the analysis. Chapter 3 describes the methodology used to conduct the study. Chapter 4 presents the results and analysis, including company specific findings, benchmark and an analysis of different future scenarios. The chapter also provides answers to the research questions. Chapter 5 discusses the main findings, the methodology and the assignment. Chapter 6 presents the conclusions and Chapter 7 provides recommendations for the industrial partner and future work based on the results of the analysis.

2 Theory

This chapter presents the theoretical background used as a basis for the analysis. It first introduces relevant analytical frameworks and sustainability-related concepts. The chapter then provides an overview of the heavy truck industry by discussing key factors that influence the transition toward more sustainable practices.

2.1 Analytical Frameworks

This section presents the analytical frameworks used to structure and support the analysis. The frameworks are used to examine sustainability from different perspectives, including future uncertainty, circularity, performance comparison and sustainability reporting.

2.1.1 Scenario Planning

Scenario planning is a method for exploring possible future developments rather than attempting to predict a single future. It is used to address uncertainty and complexity and is described as a support tool for strategy and long-term planning [16].

The method is often attributed to defence analyst Herman Kahn, who developed early scenario-based approaches in the late 1940s following the Second World War. At that time, it was used to analyse different conceivable scenarios regarding how an adversary might employ nuclear technology. The approach was later further developed within both academia and industry, where, among others, Royal Dutch Shell played an important role in establishing scenario planning as a strategic tool for business analysis under conditions of uncertainty [17].

In the literature, scenario planning is described as a process in which relevant driving forces affecting a system are identified. This can, for example, be done using frameworks such as STEEP, which enables the mapping of social, technological, economic, environmental, and political factors [18]. Subsequently, the uncertainties associated with these drivers are analysed, with a focus on their potential impact and degree of unpredictability.

Furthermore, the most critical uncertainties are described as forming the basis for the development of a scenario logic, which is structured as a two-dimensional matrix where each axis represents a key uncertainty, see figure 2.1. Based on this structure, future scenarios are constructed and subsequently analysed to develop an understanding of possible strategic implications and courses of action.

In theory, scenario planning enables organisations to envision different future scenarios and uncertainties before they occur. This is described as potentially creating a competitive advantage by enabling long-term planning and increased preparedness for potential crises. In this way, the method can contribute to greater long-term stability [16].

A limitation mentioned in the literature is that scenario planning can be influenced by cognitive biases. Despite the method's aim to broaden decision-makers' perspectives and address uncertainty, such biases may still remain in the analytical process. For example, there is a tendency to seek confirming information while underweighting contradictory evidence, which may lead to distorted scenarios. Furthermore, the narrative structure of scenarios can contribute to less probable outcomes being perceived as more plausible than they actually are [19].

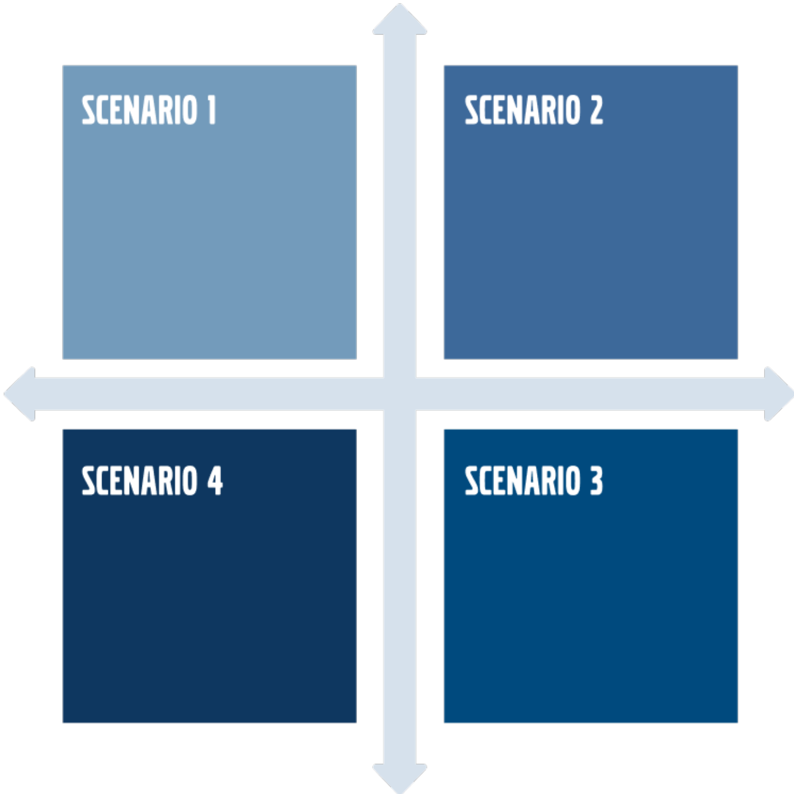


Figure 2.1: Scenario planning logic structured as two-dimensional matrix, where each axis represents a key uncertainty.

2.1.2 The 9R Framework

The 9R framework is used to describe different strategies for increasing circularity in a product chain. According to Potting et al. [20], these strategies can be ranked from higher to lower circularity. The main idea is that strategies which reduce the need for new products and materials should be prioritised before strategies that only manage waste at the end of the product lifecycle [20].

The framework includes nine circularity strategies: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover, as shown in figure 2.2. Refuse means avoiding the use of a product or material when it is not needed. Rethink concerns using products more efficiently, for example through sharing or service-based models. Reduce focuses on lowering the amount of resources and materials used in production and use. Reuse means that a product is used again for the same purpose, while Repair aims to extend the product lifetime by fixing defects. Refurbish means restoring an old product and bringing it up to date, while Remanufacture refers to using parts from discarded products in new products with the same function. Repurpose means using discarded products or components for a different function. Recycle focuses on processing materials so that they can be used again, while Recover refers to energy recovery from materials, for example through incineration [20].

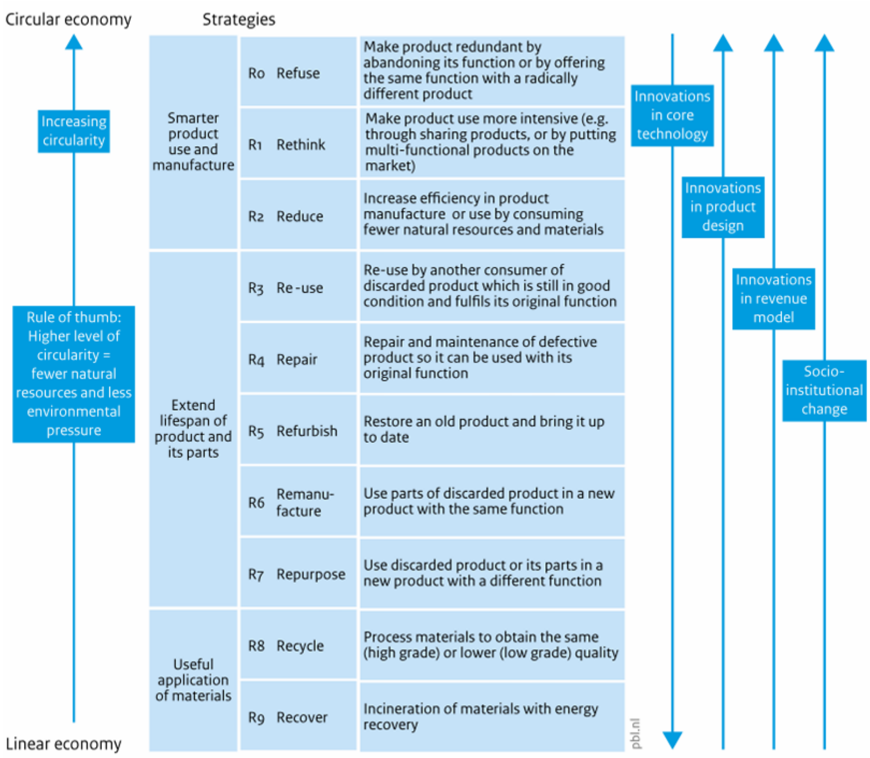


Figure 2.2: The 9 R framework ranks circularity strategies from high circularity, such as Refuse and Rethink, to lower circularity strategies, such as Recycle and Recover [20].

2.1.3 Multiple Criteria Decision Analysis

Multiple Criteria Decision Analysis (MCDA) is a set of methods used to support decision-making when several different and often conflicting criteria must be considered simultaneously. MCDA provides a structured conceptual framework for evaluating and comparing alternatives based on multiple dimensions of value. Its main purpose is to make complex decision problems more transparent by explicitly structuring trade-offs between different criteria [21].

A central theoretical component within MCDA is Value Measurement Theory, which is based on the idea that each alternative can be associated with a numerical value representing its overall desirability. This approach allows qualitative preferences to be translated into a structured quantitative representation. Within this theory, preferences are assumed to satisfy two fundamental properties. First, completeness implies that any two alternatives can be compared, and second, transitivity ensures logical consistency in preferences.

This can be handled by an additive value model, which assumes that the overall value of an alternative can be represented as the sum of its performance across multiple criteria. In this framework, each criterion contributes separately to the overall evaluation. Since criteria are often measured in different units, each criterion is first transformed into a standardized value scale, making different criteria comparable. This transformation ensures that all criteria are expressed within a common evaluative space. Each criterion is assigned a weight, which reflects its relative importance in the decision context. Weights represent trade-offs between criteria and indicate how much importance is attached to improvements in one criterion relative to another. The overall value of an alternative is obtained through aggregation, where the weighted value functions are combined into a single total value. This aggregated value allows for consistent comparison between alternatives based on multiple criteria simultaneously.

In this way, MCDA provides a theoretical framework for structuring complex decision problems, making trade-offs explicit, and supporting systematic and transparent evaluation of alternatives in multi-criteria contexts.

2.1.4 Environmental, Social and Governance Reporting Frameworks

Environmental, Social and Governance(ESG) are factors used to assess a company's sustainability related performance, as well as risks and opportunities within these areas. The growing interest in ESG factors reflects the view that such issues can affect a company's long-term performance and should therefore be considered in investment decisions [22].

To enable companies worldwide to understand and report their impacts on the economy, the environment and people in a credible and comparable way, the Global Reporting Initiative (GRI) provides standards for sustainability impact reporting [23]. The reporting standards are divided into three different levels: Universal Standards, Sector Standards and Topic Standards. The Universal standards concern company governance, human rights and how companies identify and address their most relevant impacts, referred to as material topics. Sector standards are used to enable consistent reporting on sector specific impacts and help companies outline likely material topics [24]. The Topic Standards provides guidance on how to report on topics that the company considers material, such as emissions, water, energy and waste [23]. These reporting standards help companies determine their material topics and disclose them in reports in a way that improves comparability between companies.

A method for determining material topics is the Double Materiality Assessment (DMA). Through this assessment, companies report sustainability impacts from two perspectives: financial materiality and impact materiality. Financial materiality concerns how emerging sustainability issues may create financial risks or opportunities for the company, while impact materiality concerns how the company's actions affect people and the environment [25].

For European based companies, there are additional regulations and standards that must be followed in sustainability reporting. These are called the European Sustainability Reporting Standards (ESRS), which are a part of the Corporate Sustainability Reporting Directive (CSRD) [25].

For reporting greenhouse gas emissions, there is a specific protocol, the GHG protocol, which provides a framework for categorizing emissions into three different scopes. Scope 1 refers to direct greenhouse gas (GHG) emissions from a company's own operations. Scope 2 accounts for indirect emissions from purchased energy and electricity. Scope 3 refers to other indirect emissions across the value chain, including emissions from the use of sold products [12].

In the trucking industry, on-road operation and maintenance represent the dominant part of life cycle emissions across vehicle classes and powertrain categories [26]. For truck manufacturers, these emissions are reflected in Scope 3 emissions, since they occur during the use of sold products. Therefore, Scope 3 emissions are of particular importance in this study, as they capture that part of the life cycle where the largest share of climate impact occurs and where reductions can have the greatest impact on total life cycle emissions.

Although Scope 3 emissions represent the largest share of life cycle emissions for heavy truck manufacturers, energy consumption in manufacturing is still an important sustainability indicator. Total energy consumption reflects the company's resource efficiency within its own operations. Truck manufacturing is a complex and energy intensive process [27].

2.2 Barriers to Sustainability Transition in the Heavy Truck Industry

To understand the heavy truck industry and its transition toward more sustainable practices, it is necessary to examine the main barriers affecting this transition. These barriers can be categorized into organisational, financial, technological, and regulatory factors [28].

2.2.1 Organisational Barriers

Organisational factors are strongly influenced by how companies perceive the credibility of political governance in relation to sustainable transition. Rogge and Dütschke [29] show that policy credibility is crucial for companies willingness to carry out long-term investments and innovations related to low-carbon transitions. This is also relevant for heavy truck manufacturers, which depend on long-term regulatory predictability when investing in low-emission technologies, production systems and supply chains. In this context, credibility refers to the extent to which companies perceive the policy mix as reliable and trustworthy over time [29].

According to Rogge and Dütschke [29], companies perceptions of policy credibility are primarily shaped by coherence and consistency. Coherence means that policy processes and implementation are coordinated, while consistency means that political goals and policy instruments support each other rather than create contradictions. When these elements are lacking, companies confidence in the long-term direction of the transition decreases [29].

For companies to be able to organise themselves and invest in sustainable solutions, a credible and consistent policy mix is therefore required. Rogge and Dütschke [29] also show that reduced levels of ambition and changes in central policy instruments can weaken companies perceptions of policy credibility, which affects their willingness to act with a long-term perspective in the transition [29].

Geopolitical instability also affects how companies organise their sustainability transition [30]. Since heavy-truck manufacturers depend on global supply chains for components, materials and technologies, political tensions, trade barriers and supply disruptions can create uncertainty in long-term planning. Previous research shows that geopolitical disruptions influence supply chain management decisions and increase the need for resilience, diversification and reduced dependency on vulnerable external actors.

2.2.2 Financial Barriers

Financial factors are also something to consider and a good example today is the evolvement toward electrified road transport. Gillström [31] show that the logistics industry is characterized by low margins and high demands for cost efficiency, which makes investments in battery electric trucks difficult to justify when the purchase cost remains significantly higher than that of conventional vehicles. The study also shows that battery electric trucks may involve uncertainties regarding, for example, service costs, battery lifetime and residual value, making the total cost picture difficult to assess [31].

A further financial barrier is that electrification may affect the operational efficiency of logistics firms. Gillström [31] highlight that limited range, longer charging times and insufficient charging infrastructure may reduce the flexibility and reliability of transport operations. Since low cost and high logistics performance are important competitive advantages for logistics firms, these factors may reduce the willingness to transition to battery electric vehicles (BEVs) [31].

Charging infrastructure also creates financial interdependence between different actors. Raoofi et al. [32] describe the development of electric trucks and charging infrastructure as a "chicken-and-egg" problem: without a sufficiently dense network of charging stations, demand for electric trucks remains low, but when few electric trucks are in use, demand for charging remains low, which reduces the incentives for private actors to invest in charging infrastructure [32].

This means that the market on its own may struggle to accelerate both vehicle adoption and infrastructure expansion simultaneously. Raoofi et al. [32] therefore show that policy interventions, particularly support for charging infrastructure, can play an important role in increasing the use of electric heavy trucks. The study also shows that subsidies for charging stations can lead to a clear increase in the adoption of electric trucks [32].

2.2.3 Technological Barriers

Technological development is a central part of climate mitigation. The Blanco et al. [33] IPCC highlights innovation, technology development and technology transfer as important factors for supporting low-emission transitions. The report also emphasizes that the diffusion of climate-related technologies depends on research and development, technical capabilities, access to knowledge and cooperation across the innovation chain [33].

China's development of electric vehicles illustrates how technological change can reshape competition in the transport sector. Chen et al. [34] describe how China's electric vehicle market has developed through both official electric vehicles and broader low-cost electric mobility solutions. Although regulation and policy support have played a role, the key point is that Chinese manufacturers have developed electric vehicle capabilities that challenge established European and American vehicle producers [34].

This development is now also moving into heavier vehicle segments. Ke et al. [35] show that China's zero-emission commercial vehicle development includes buses, logistics vehicles, port vehicles, airport vehicles and vehicles used in key industries. Shenzhen is highlighted as an example where electric buses, new energy logistics vehicles and electric tipper trucks have been deployed at large scale [35].

The technological transition also creates new dependencies on critical materials and battery-related supply chains [36]. Battery electric vehicles require materials such as lithium, nickel, manganese and cobalt, which makes technological development closely connected to the availability and control of these resources. Recent research shows that the lithium-ion battery supply chain is highly concentrated and heavily dependent on China, particularly in relation to battery materials and production capacity.

2.2.4 Regulatory Barriers

Jelti et al. [28] explain that political actors at local, national and international levels can influence the transition by shaping policies, allocating funding and creating conditions that affect transport choices. The study also highlights that a better understanding of the benefits of sustainable transportation can improve alignment between institutions and stakeholders during the policy-making process [28]. This suggests that regulation should not only be understood as a restriction on companies, but also as an enabling mechanism that can reduce uncertainty, coordinate market actors and support investments in sustainable transport solutions.

This enabling role of regulation is reflected in several of the barriers discussed in the previous sections. From an organisational perspective, companies depend on credible and consistent policy signals in order to justify long-term investments in low-emission technologies, production systems and supply chains. From a financial perspective, public support may be needed to reduce investment barriers and avoid market coordination problems, such as the chicken-and-egg problem between electric truck adoption and charging infrastructure. From a technological perspective, regulation and industrial policy can create incentives for firms to prioritise certain technologies, thereby accelerating development across the industry.

2.3 Application of the Theoretical Frameworks

The theory presented in this chapter forms the analytical basis for the results and analysis in Chapter 4. Scenario planning is used to examine how geopolitical uncertainty and sustainability regulations may shape future strategic conditions in the heavy truck industry. The 9R model supports the analysis of circularity and resource efficiency, while MCDA and ESG-based indicators are used to structure the benchmarking and weighted scoring of the studied companies. The industry-specific barriers presented in Section 2.2 provide context for interpreting differences between companies and for understanding the conditions that influence their sustainability transition. Together, these theoretical perspectives connect the report's analytical tools to the research questions and provide a structured foundation for evaluating both current sustainability performance and future strategic implications.

3 Methodology

The methodology of this study was designed to provide a broad and structured understanding of sustainability practices within the heavy truck industry. Since the research questions involve both strategic and operational aspects, the study combines several complementary methods in order to collect, analyse and compare data from multiple perspectives.

3.1 Methodological Process

The project was an exploratory study that combined both qualitative and quantitative methods. The purpose of this mixed-method approach was to gain a comprehensive understanding of the subject. By combining different methods, the study enabled the inclusion of multiple perspectives and reduced the risk of bias associated with relying on a single data source. Furthermore, the approach allowed for triangulation where insights from different methods could be compared and validated, thereby increasing the robustness and credibility of the results. The study consisted of four main methodological components:

- Literature Study
- Interviews
- Workshop
- Analytical Frameworks

The main components were conducted iteratively and in an overlapping manner, see Figure 3.1. Knowledge was transferred between these components and the methodology was adjusted and improved during the project.

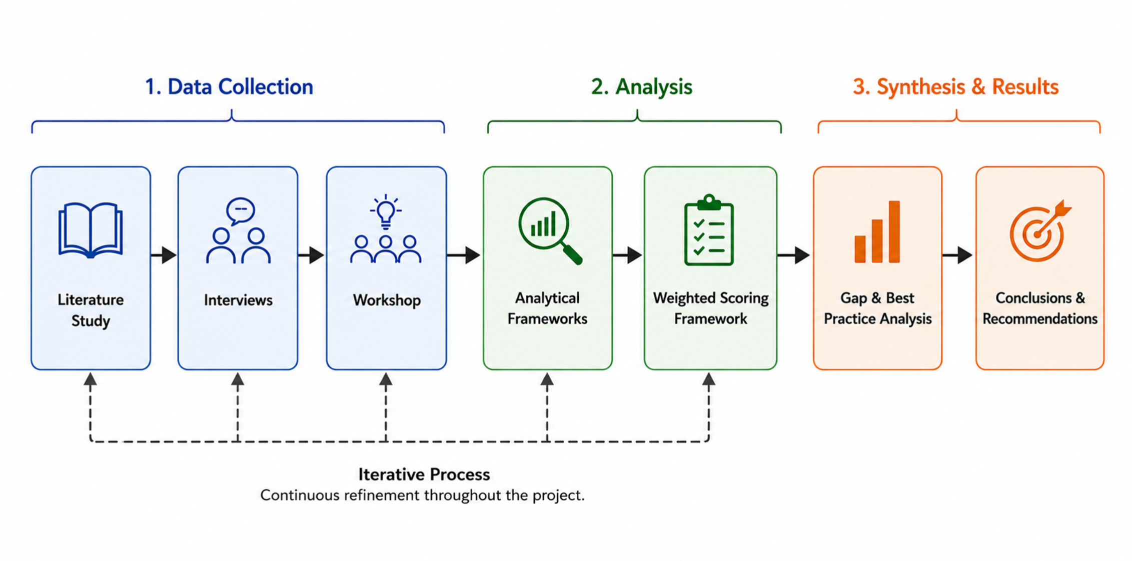


Figure 3.1: Methodological Process Overview. (Created with ChatGPT, 2026)

The project started with a literature study to establish a broad theoretical foundation, which was used to refine research questions, interview guides and the selection and application of analytical frameworks. This process was conducted iteratively throughout the majority of the project. Once an initial overall understanding of the research area had been developed, interviews were conducted to deepen the understanding of key topics identified in the literature review.

Insights from the different methodological components were combined and triangulated to establish a shared knowledge base. This knowledge was subsequently applied within the analytical framework to generate new insights and conclusions. The methodological components complemented each other and contributed to a comprehensive understanding of the research problem. Finally, a weighted scoring framework was developed through a systematic synthesis in which insights from the literature review, interviews and analytical frameworks were integrated and critically evaluated. The criteria included in the weighted scoring framework were iteratively reviewed and refined throughout the project to ensure their effectiveness and appropriateness in addressing the research questions and fulfilling the project objectives.

3.2 Cooperation with Penn State University

The project was carried out in collaboration with six students from Pennsylvania State University, hereafter called Penn State. To coordinate the work and maintain continuous communication throughout the project, weekly online meetings were held with the students from Penn State. In addition to the online collaboration, the project also included a visit to USA and Penn State. The visit included joint workshops and further research together. This strengthened the cooperation and enabled more in-depth discussions regarding the project direction and findings.

The collaboration was mainly focused on the research phase of the project, the development of the weighted scoring framework and the final recommendations to Volvo Group. The companies included in the study were divided among the project participants, where one Swedish student and one American student were paired together for each company to encourage international cooperation and knowledge exchange. This setup enabled the teams to jointly conduct research and analyse the selected company and its metrics.

The collaboration also benefited from the participants' different academic backgrounds, including Industrial Engineering and Management, Mechanical Engineering, Industrial Design Engineering, Global Systems Engineering and Energy Engineering. The combination of different educational perspectives and nationalities contributed to a broader understanding of the studied topics and enabled discussions from multiple viewpoints.

Although the project were closely connected and based on a shared research foundation, the deliverables and report structures differed between the universities. The students from Penn State conducted a Capstone project with a more consultant-oriented approach, focusing more on practical recommendations and actionable outcomes. In contrast, the bachelor thesis at Chalmers required a stronger academic foundation with greater emphasis on methodology, research background and analytical reasoning behind the conclusions. Despite these differences, the projects complemented each other well and the collaboration resulted in a shared final presentation for Volvo Group where the overall findings and recommendations from the project were presented jointly.

3.3 Selection of Companies

Since Volvo Group served as the industrial partner and provided the initial project context, Volvo Group was used as the baseline for comparison with the other companies. The other companies were chosen based on similar market positions in the markets included in the study. Regarding the relevant geographical markets, Volvo Group indicated that North America, Asia and Australia were of interest in the final report. In addition to similar market position and geographical relevance the companies needed to have publicly available sustainability data. Based on these selection criteria, the companies presented in Table 3.1 were included in the study.

Table 3.1: Overview of companies

Company name	Main researched geographical market
Volvo Group	North America, Europe
Daimler	North America, Europe
PACCAR	North America, Australia
Isuzu	Asia
MAN (Traton Group)	Europe, Asia
Scania (Traton Group)	Europe
International (Traton Group)	North America

3.4 Literature Study

A structured literature study was conducted to establish a theoretical foundation for the project. To find literature, relevant main categories and keywords were defined to suit both the scope and delimitations in order to find relevant sources. Frequently used keywords included sustainability, heavy trucks, electric heavy trucks, road freight, decarbonisation, and truck manufacturing.

To ensure high quality and reliable sources, the primary database used was Scopus, due to its indexing of peer-reviewed scientific publications. This was complemented by searches in Google Scholar and the Chalmers Library database to broaden the scope of the literature search. In addition, AI-based tools, such as Scopus AI, were utilized to support the identification of relevant literature. These tools enabled a more efficient screening process.

Initially, sources were evaluated based on their titles. If deemed potentially relevant, abstracts were reviewed to assess relevance to the research purpose. Finally, full-text articles were examined to determine their suitability for inclusion. Inclusion criteria required sources to be: peer-reviewed, relevant to the heavy truck industry and published in recent years to ensure up-to-date insights, given the rapid technological development in the field.

The literature base consisted of scientific articles, industry reports, regulatory documents and publications from governmental and non-governmental organisations. While the primary focus was on recent publications, some older sources were included when they provided essential theoretical frameworks or widely accepted models. In total, approximately 70 sources were included in the study.

The literature review was conducted iteratively, see Figure 3.2, meaning that insights gained throughout the process were continuously integrated into the project. This enabled ongoing refinement of the research questions and the development of interview guides, ensuring alignment between the theoretical framework and the empirical investigation.

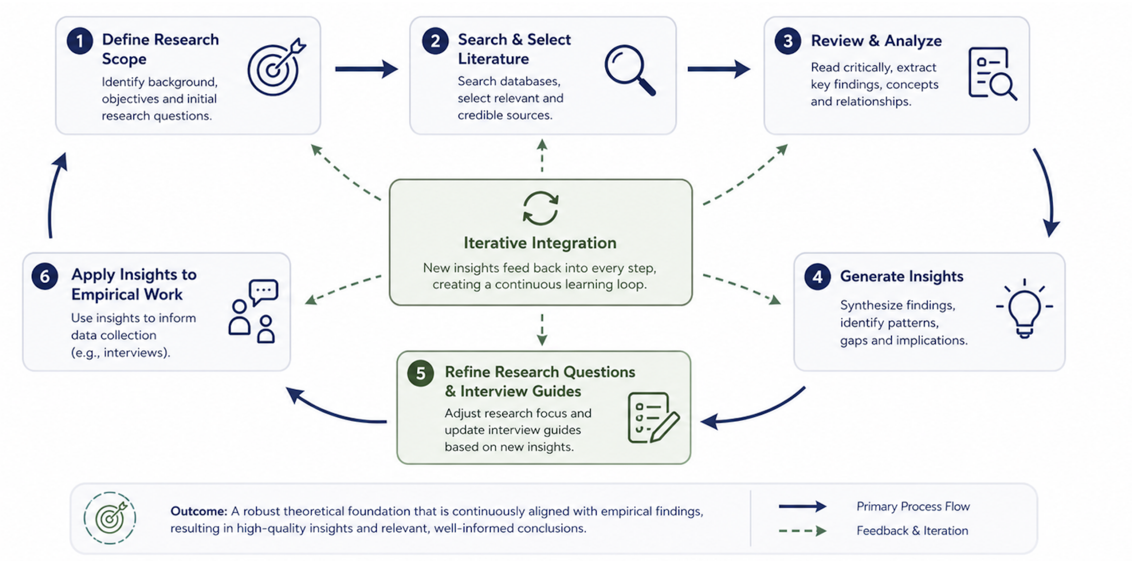


Figure 3.2: Iterative Literature Review Process. (Created with ChatGPT, 2026)

3.5 Interviews

Semi-structured interviews were conducted with the following individuals:

- Representatives from Volvo Group, to gain insight about their operations and how they set their sustainability goals and work to achieve them.

- Representatives from Volvo Group's competitors, to gain insight into how competitors work with sustainability practices compared to Volvo Group, and to see which similarities and differences exist.

The interviews were based on an interview guide developed from the research questions and the literature review. It contained predefined questions that were asked in all interviews. However, the interview approach allowed for follow-up questions in order to obtain more detailed information when relevant [37]. The interview guide is shown in appendix A.1.

All of the selected companies were contacted for potential interviews. Interviews were conducted with the companies that responded positively. All of the interviews were conducted online through Microsoft Teams and recorded. The interviews were transcribed using AI services and manually reviewed for accuracy. The preferred interviewees were individuals working with sustainability and who had at least several years of experience at the company to have a good understanding of their operations and strategy. The interviews that were conducted as part of the study are presented in Table 3.2 below.

Table 3.2: Overview of interviewees.

Respondent name	Role	Company	Length (min)
Respondent 1	Director of Environment	Volvo Group	35
Respondent 2	Sustainability Strategy Manager	Scania	45
Respondent 3	Director of Sustainability	PACCAR	59

The interviews were subsequently analysed by systematically reviewing the transcripts. Relevant themes and strategies across the different interviews were identified and incorporated into the results of the report. The interviews were particularly useful in providing context and explaining why certain sustainability strategies are adopted, as well as how they are implemented in practice. This complemented the document-based analysis, especially in areas where written sources did not provide sufficient detail.

3.6 Workshop

As part of the methodology, a Strategic Foresight Workshop was included to complement the literature study and interviews. The purpose was to capture forward-looking insights and emerging trends relevant to the future development of national security, geopolitics and industrial supply chains.

The workshop included sessions on global trends, strategic risk management, advanced manufacturing, supply chain security and geopolitical developments, a picture from the workshop is shown in figure 3.3. These areas are relevant to the heavy truck industry, particularly in relation to sustainability transitions and future uncertainties.

Figure 3.3: Strategic Foresight Workshop. (Emil Sirsjö, 2026)

The workshop generated qualitative insights in the form of panel discussions and case-based exercises. The workshop broadened the perspective of the study and reduced reliance on retrospective or company specific data, thereby strengthening the validity of the analysis.

The insights from the workshop were mainly incorporated into the scenario analysis where different perspectives and aspects from experts in different fields contributed to the identification of key drivers and uncertainties.

3.7 Analytical Frameworks

The following different analytical frameworks were used to analyse the collected data and information:

Scenario Planning
Scenario Planning was applied to anticipate potential market reactions in the heavy truck industry in response to possible future changes in regulations and demand [16]. The framework integrated insights from both literature and interviews. The

input to this framework consisted of data from the literature review, as well as insights from interviews and the workshop with industry actors.

The framework was applied by first identifying key external drivers affecting the industry. These drivers were structured using the STEEP framework, covering social, technological, economic, environmental and political factors. Based on this analysis, two critical uncertainties were selected: the level of support for the energy transition and the state of relations between China and the Western world. These uncertainties were then combined in a 2 x 2 matrix to develop four plausible future scenarios for the heavy truck industry.

The output of the scenario planning analysis was a set of four scenarios illustrating how different combinations of regulatory support and geopolitical conditions may affect electrification, supply chain strategies, technological development and OEM competitiveness. The scenarios were used to compare potential strategic implications and to identify robust strategic responses, such as increased supply chain resilience, control over critical technologies, modularization and flexibility between different drivetrain technologies.

9 R

9 R were used to analyse how the studied companies address sustainability and circularity across the product lifecycle [20]. The input consisted of company-specific data collected from interviews, sustainability reports, and other sources describing operational practices, business models and life cycle strategies. The framework was applied by evaluating each company against the nine circular strategies: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover. This allowed for a systematic mapping of their circularity efforts. The output of this analysis was a comparative assessment of the companies' performance in terms of circularity, highlighting strengths, weaknesses and differences in sustainability strategies across the value chain.

MCDA

MCDA was used as a framework to support the comparison of companies across multiple sustainability dimensions. The method enables structured evaluation when several criteria, both qualitative and quantitative, must be considered simultaneously.

The input to this framework consisted of sustainability related data collected from the literature review and interviews. The framework was applied by identifying key evaluation criteria relevant to the research questions, reflecting different aspects of sustainability performance.

MCDA was used to structure the comparison and make trade offs between different criteria. The output of this framework was a structured basis for evaluating and comparing the sustainability performance of studied companies.

3.8 Analysis of Data and Presentation

Weighted Scoring Framework
To operationalize the MCDA approach, a weighted scoring framework was developed and applied to assess how well different companies performed regarding the analysed sustainability parameters in the heavy truck industry. The framework was constructed through a systematic synthesis of insights from the literature review, interviews and applied analytical frameworks.

This synthesis resulted in a set of categories and sub-categories that captured key sustainability criteria and were combined into a joint score for each company in the study.

The scoring framework consists of two main categories that capture Product & Supply Chain and Operations. The environmental metrics were primarily based on ESG-related indicators, inspired by the European Union's sustainability frameworks and reporting standards, due to their transparency, comprehensiveness and strong data availability, especially for European companies. Each metric was assigned a weight reflecting its relative importance. Furthermore each metric was scored on a scale from 1 to 5. The scores were estimated based on the relative performance of the companies compared to one another, in order to achieve a reasonable and consistent distribution of scores across the evaluated criteria, see Appendix B.1. To enable comparison between companies of different sizes, some metrics were calculated on a per vehicle basis, the calculations for each company is shown in Appendix C.1. The weighted scores were then aggregated to generate an overall performance of each company.

As part of the evaluation, areas with weak or insufficient underlying data were identified. In such cases, the analytical approach was iteratively refined for these areas with a focus on strengthening the analytical basis before proceeding with the analysis. The suitability of the selected criteria and weights was continuously reviewed and refined throughout the project to ensure relevance and consistency. The weighting of criteria was primarily informed by insights from the literature review and was iteratively tested and adjusted during the analysis.

Gap and Best Practice
Best practice analysis was used to identify how the most sustainable firms operate regarding the analysed parameters in the heavy truck industry.

In addition, a gap analysis was conducted to assess areas where Volvo Group does not perform at the same level as the highest performing companies. Both of these analyses were based on comparisons of the different studied companies and their respective scores from the weighted scoring framework, see figure 3.4.

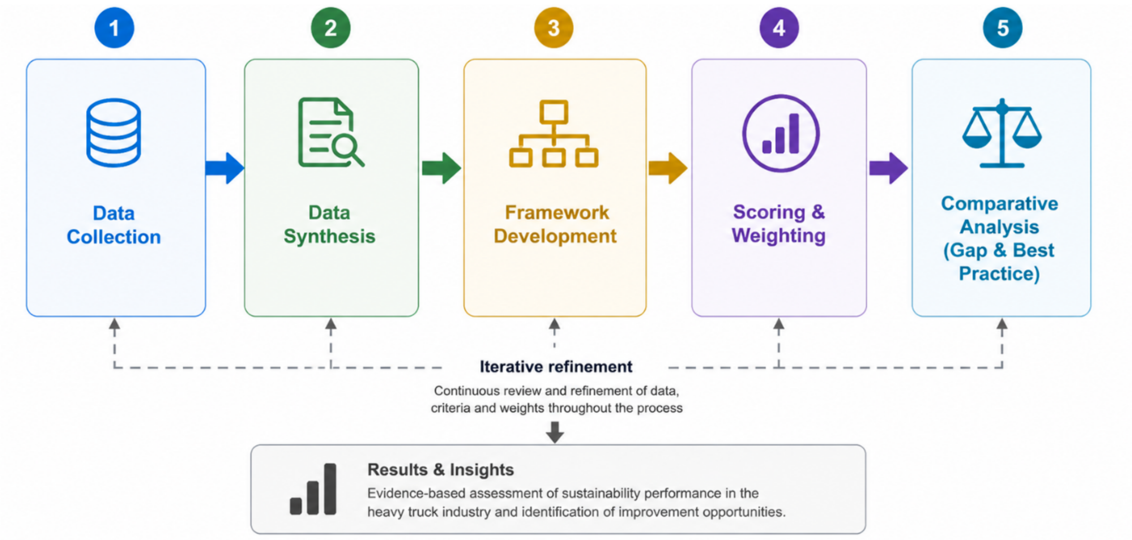


Figure 3.4: Analytical Process Overview. (Created with ChatGPT, 2026)

3.9 Validity and Reliability

Validity was enhanced through triangulation of data from multiple sources including literature and interviews, which reduced risk of systematic bias and increased the robustness of the conclusions. Reliability was supported by applying a standardized approach across all data collection methods. For interviews, this involves using the same interview guide for all participants, while for the literature study, a systematic screening process, with predefined selection criteria was applied.

3.10 Ethical Aspects

Although this study was conducted on behalf of Volvo Group, the benchmarking and analysis were carried out with academic neutrality. The results were not intended to be influenced in favor of the industrial partner, and Volvo Group was assessed according to the same criteria as the other OEMs included in the study.

The project involved international collaboration with students from Penn State, which required consideration of differences in academic practice, communication routines, and cultural norms. To address this, the project group maintained a shared understanding of how information should be collected, handled, and used in the report.

Interviews were conducted with informed consent. The interviewees were informed about the purpose of the study and how the information would be used. Interviewees were anonymized to protect personal information.

The benchmarking process relied extensively on information published by companies in open sources. Much of this material consisted of annual and sustainability reports, press releases, and other forms of corporate communication that may present the companies in a favorable way. Therefore, the material was interpreted critically, and attention was given to potential bias, differences in reporting detail, and variation in how companies presented their sustainability performance.

3.11 Artificial Intelligence

AI-based tools were used as support during the project. This primarily included assistance with language refinement, idea generation, structuring of text and to support the literature search process by identifying potentially relevant sources and improving the efficiency of screening. AI tools were also used to create images and illustrations included in the report.

All AI-generated suggestions were critically reviewed and validated by the authors to ensure accuracy, relevance, and academic integrity. AI tools were not used as primary sources of information, and all referenced material in the report originates from credible and verifiable sources.

3.12 Methodological Summary

Together, these methods and analytical frameworks form the foundation of the study and complement each other throughout the research process. The literature study provides the theoretical background, while interviews and workshops contribute with practical insights and industry perspectives. The analytical frameworks enable a structured evaluation of sustainability performance, future uncertainties and strategic differences between companies. By combining these approaches, the study is able to create a comprehensive basis for the results, benchmarking and recommendations presented in the report.

4 Results and Analysis

This chapter presents and analyses the sustainability performance of the selected heavy truck manufacturers. First, the company-specific results are presented to show how each firm integrates sustainability into its strategy, product development, operations, and business models. The chapter then compares the companies through a weighted benchmarking framework, followed by a gap and best-practice analysis. Finally, the results are analysed in relation to key sustainability metrics, technological solutions and future strategic challenges shaped by regulation and geopolitical uncertainty.

4.1 Company-Specific Sustainability Results

This section presents the company-specific sustainability results for the manufacturers included in the study. Each company is described separately, with focus on identified sustainability targets, strategic priorities, operational measures and technological approaches relevant to the environmental scope of the report. The purpose is to establish a factual basis for the subsequent benchmark and comparative analysis.

4.1.1 Volvo Group

Strategy, Governance and Materiality

According to Respondent 1, Volvo Group identifies climate change as one of the most significant sustainability challenges facing the company. In response, the company has committed to aligning with the goals of the Paris Agreement by aiming to achieve net-zero greenhouse gas emissions in 2040. As part of this ambition, Volvo Group states that it aims to offer 100% fossil free vehicles by 2040.

Volvo Group uses a double materiality assessment (DMA) to evaluate the risks, opportunities and impacts associated with different sustainability topics. The results of this assessment form the basis for determining which topics are disclosed in the sustainability report. According to Volvo Group, the assessment includes all topics covered by the European Sustainability Reporting Standards (ESRS), as well as company specific topics [38].

Climate Strategy and Targets

To support the sustainable transition, Volvo Group has established science-based climate targets verified by the Science Based Targets initiative (SBTi), using 2019 as the baseline year. For trucks, the interim target is to reduce Scope 3 (use phase) emissions per vehicle-km by 40% by 2030. According to Volvo Group, the reduction achieved by 2025 amounted to 10% compared with the 2019 baseline. The company states that this improvement was mainly driven by increased fuel efficiency rather than alternative drivetrains [38].

The strategy for reaching the interim targets and ultimately net-zero emissions includes introducing lower carbon technologies, improvements in overall fuel and energy efficiency, and shifting towards fuels with lower greenhouse gas intensity. Respondent 1 emphasised that improving energy efficiency forms the basis of the company's decarbonisation efforts. The technologies highlighted by Volvo Group include battery electric and hydrogen fuel cell electric vehicles. In parallel with the development of new technologies, the company also works to improve the efficiency of existing vehicle technologies. According to Volvo Group, this is mainly pursued through improvements in the driveline and combustion engine, as well as through enhanced aerodynamics and energy recuperation [39]. The transition to less greenhouse gas intense fuels is highly dependent on the development of external infrastructure, including electricity supply, charging, and hydrogen infrastructure. To support this transition, Volvo Group states that they engage in dialogue with both policymakers and customers [38].

Volvo Group also outlines an order of priority for achieving net-zero value chain emissions: first, to eliminate emissions through energy efficiency improvements and the introduction of new technologies. Second, to replace fossil emissions with biogenic alternatives and finally, to counterbalance remaining emissions through measures such as carbon removal and storage [38].

Decarbonisation of the Value Chain (Scope 3)

A key insight in Volvo Group's climate strategy is that approximately 95% of life cycle emissions originate from the use phase, making Scope 3 the primary focus of decarbonisation.

As a part of Scope 3 emissions, upstream value chain emissions from purchased goods and services are included. As vehicle use phase emissions decrease, the climate impact of purchased goods becomes increasingly important. Volvo Group states that reductions in this area are pursued through supplier engagement to reduce operational greenhouse gas emissions, the sourcing of fossil-free and low carbon materials and the design for lower carbon components and products. As part of this work, the company has committed to sourcing low carbon aluminum and near zero emission steel by 2030. According to Volvo Group, emissions from purchased goods and services were 24% lower in 2025 compared to the baseline year, 2019. However, year-to-year changes are affected both by supplier initiatives and by sales volumes [38].

Operational Emissions (Scope 1 and 2)

Although emissions from own operations (Scope 1 and 2), make up a relatively small share of Volvo Group's total emissions, the company describes several measures to decarbonise these activities. These include increasing energy efficiency in operations, expanding renewable energy sourcing and adapting processes to renewable fuels. Volvo Group applies the energy management standard ISO 50001 and has established internal targets for annual energy savings. This target was set in 2021 and aimed for implemented measures to save 150 GWh annually by 2025. By the end of 2025, the implemented measures had resulted in annual energy savings of 107 GWh, meaning that the target was not fully achieved. The company states that new energy efficiency targets will be developed in 2026. Volvo Group also reports that 56% of the energy used by the Group in 2025 came from renewable sources [38].

The total greenhouse gas emissions from Volvo Group's own operations were in 2025 33% lower than in 2019. Within this, Scope 1 emissions were reduced by 20%, Scope 2 emissions were reduced by 50%, mainly because of higher proportion of renewable fuels at sites and higher share of renewable energy respectively [38].

Circular Economy and Resource Use

Volvo Group identifies waste from its own operations as the most significant issue. The company states that they are aiming to avoid waste being sent to landfill and instead make materials available for recycling and reuse. Volvo Group has set an ambition for 55 industrial operation sites to be certified as landfill free, According to the company, a landfill free site is one that works across the stages of the waste hierarchy in order to reduce the negative impacts of waste generation [38].

4.1.2 Daimler

Materiality Assessment

To align sustainability with core business strategy, Daimler uses a double materiality assessment (DMA)(see figure 4.1). The assessment is conducted through a structured five-phase process. Phases 1-3 establish a baseline by combining internal data with external requirements, such as the European Sustainability Reporting Standards (ESRS). During these phases, Daimler maps its entire value chain and engages with key stakeholders to identify and prioritise relevant sustainability topics. In Phase 4 and 5, identified topics are translated into specific impacts, risks, and opportunities. These are subjected to a rating process where internal experts evaluate the likelihood of each factor. The rating process allows Daimler to prioritise issues that pose the greatest risk or offer the most significant strategic opportunities. At the end, the findings are validated by the board of management that ensures that the sustainability goals are integrated into operational- and strategy work [40].

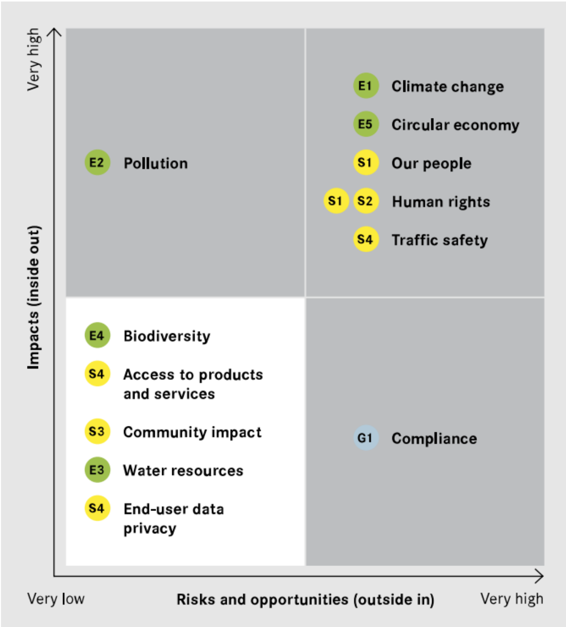


Figure 4.1: DMA matrix used by Daimler showing ESG topics and their impacts, risks and opportunities [40].

Climate Strategy and Targets

Daimler's environmental targets are primarily guided by regulatory requirements, which establish a baseline for the company's operations. In addition to compliance, the company emphasizes a proactive approach through innovation and product development aimed at reducing emissions and environmental [40].

Daimler is focusing on both environmental- and climate protection. Climate protection involves minimizing the emissions released from the "tank to wheel" phase, that is to say no emissions when the vehicle is being driven. Daimler is devoted to the Paris Climate Agreement, working towards making transport CO_2 free. By 2039, they are aiming to be locally CO_2 free in Europe, Japan and the US, and worldwide by 2050 [40].

The other area of focus, environmental protection, focuses more on the production aspect. By 2030, Daimler is expecting to use a minimum of 55% of energy from renewable sources. Additionally, Daimler is pursuing a 42% reduction in production related CO_2 emissions with regard to the time period between 2021 to 2030. Daimler aims to achieve net-zero emissions from all production sites around the world by 2039 [40].

Current data from 2025 shows a progress towards these targets. Green energy production stands at 78.1% (target 100% by 2030), and in-house energy production has reached 3.4% (target 5%). Total renewable energy use was 35% in 2025, with a target of >55% by 2030. In 2025, non-renewable energy consumption amounted to 536.6 GWh [40].

To reach the emissions goals, Daimler is currently offsetting CO_2 emissions for Scopes 1 and 2. Primarily offsetting is used for the European and Japanese production sites. Daimler states that the offsetting is used as a transitional action towards CO_2 free production. All projects meet the high standards of the Gold Standard, a leading benchmark for certifying climate and development impact. They also support sustainable social and environmental development in host countries [40].

Governance and Incentives Driving the Sustainable Transition

A critical component in ensuring that Daimlers' sustainability goals are pursued across the organisation is the integration of these targets into the executive remuneration system. This serves as a primary steering mechanism to align management's focus with long-term strategy. For the 2025 financial year, sustainability related performance indicators constituted 16% of the targets within the variable remuneration for the Board of Management and senior leadership. This represents a significant increase in strategic weight compared to 2024, where emission-based targets accounted for 12% of the total targets [40].

A central KPI within this framework is the unit sales of locally CO_2 free vehicles. By directly linking financial incentives to the market success of zero-emission products, Daimler states that the transition toward decarbonisation is prioritised in strategic decision making [40].

To reach the goals Daimler is implementing several changes to their business model, supply chains and production sites. The general responsibility lies with the Corporate Sustainability Board (CSB). They focus on strategic choices that support circular economy, climate- and environmental protection. Subsequently, the board helps Daimler strive towards sustainability increase that is aligned with overall strategy, company's values and stakeholder interests [40].

To create transparency in the supply chain, Daimlers' suppliers answer a questionnaire from the Carbone Disclosure Project (CDP). The CDP questionnaire collects data on suppliers environmental impact. In 2025, 63.6% of all purchased material was covered by companies that participated in the CDP. Daimler suggests that the results from the questionnaire helps to prioritise decarbonisation efforts within the supply chain. It also creates a way to benchmark the suppliers and track year on year performance [40].

4.1.3 PACCAR

Materiality Assessment

PACCAR's sustainability approach is closely integrated into the company's operations. Rather than being treated as a separate function sustainability is embedded within risk management and strategic planning. A central component for this approach is the Double Materiality Assessment (DMA) which is conducted annually. The DMA is used to form strategic decision-making, and to support risk prioritisation and resource allocation. According to Respondent 3, this reflects a shift from sustainability as a "side initiative" to a core business function [41].

Stakeholder engagement is also described as something crucial for both the sustainability strategy and the DMA. PACCAR engages with investors, regulators, employees, customers and community partners through various channels and brands. This is intended to ensure that their sustainability work and ambitions matches global standards and stakeholder expectations [41].

Climate Targets and Performance

PACCAR has established several science-based targets for its global facilities for the period from baseline year 2018 to the target year 2030. For Scope 1 & 2 emissions the target is to achieve a 35 % absolute reduction in CO_2 emissions. For Scope 3 the target is to achieve a 25 % reduction in product use greenhouse gas emission in CO_2 emissions per vehicle kilometer (well-to-wheel). PACCAR also aims to achieve vehicle recyclability rates above 90 % and material recoverability above 95 % [41].

Current performance indicates that PACCAR is on track to meet its Scope 1 and 2 targets, with emissions reduced by 22,5 % so far since the baseline year. In contrast, Scope 3 emissions have increased by 6.7 % over the same period [41].

According to Respondent 3, reductions in Scope 1 and 2 emissions are mostly driven by increased use of renewable energy and improved energy efficiency. Scope 3 emissions have on the other hand remained high due to their dependence on customer usage and continued dominance of non-electric trucks [41].

Practices Supporting Sustainable Development

PACCAR has identified three main factors to further reduce these emissions and decouple greenhouse gas emissions from energy consumption. These are to increase use of renewable electricity, electrifying equipment and implementing energy efficiency project aligned with ISO 14001 standards. To address this, PACCAR continues to invest in technology development and the production of more efficient diesel engines, while also transitioning towards zero-emission battery electric and hydrogen-powered vehicles [41].

Market share development is also described as an indirect indicator of sustainability performance. Sustainability related factors, such as efficiency, environmental standards and regulatory compliance are also increasingly important in customer purchase decision. As a result, competitiveness and sustainability are closely linked according to Respondent 3. Regulations is also described as as a driver of change rather than a disruptive force, requiring continuous adaptation to evolving requirements through multiple jurisdictions [41].

Finally, Respondent 3 emphasized that PACCAR does not rely on a single solution to address sustainability challenges. Improvements are instead achieved through incremental developments across multiple areas of business. This reflects a systems-oriented approach where overall performance depends on the combined effect of several factors. These include, for example, aerodynamics, tire selection, powertrain optimisation, digital route planning and driver behaviour [41].

4.1.4 Isuzu

Sustainability Strategy and Long Term Vision

Isuzu's sustainability strategy within the heavy truck industry is framed through its Environmental Vision 2050, which sets out the company's long-term environmental ambitions. To determine the direction of its long-term environmental strategy, Isuzu conducted a scenario analysis extending to 2050. This analysis was based on climate projections from the Intergovernmental Panel on Climate Change (IPCC) and socioeconomic scenarios derived from IPCC and International Energy Agency (IEA) data [42]. The environmental ambitions include achieving net-zero greenhouse gas emissions across the product life cycle and from the company's own operations, and full recycling of waste and end-of-use vehicles by 2050. In addition, the vision include broader commitments related to operational and product safety, and reliability, as well as the conservation of native biodiversity within local communities [43].

Operational Roadmap

Isuzu describes its future product strategy as a multi-pathway approach, whereby different powertrain technologies are developed in parallel to address varying regional conditions and use cases. As an intermediate step toward these long term ambitions, Isuzu introduced its 2030 Environmental Roadmap, which translates the 2050 vision into more specific targets and actions. The roadmap includes a target to halve Scope 1 and 2 emission relative to 2013 levels through reduced energy use, increased adoption of cleaner energy sources and technological improvements. In operational terms, this involves measures such as streamlining processes, optimising equipment operation and improving energy efficiency in manufacturing activities. The roadmap also emphasizes the development of a carbon neutral vehicle lineup adapted to varying regional needs and operating conditions. Furthermore, the roadmap highlights circularity through resource efficiency, stricter management of environmental outputs such as waste, emissions and wastewater [43].

Building on this approach, differences in operating patterns, infrastructure availability and market needs make it unlikely that a single technological solution will be suitable across all segments and regions. Isuzu therefore combines battery electric vehicles, hydrogen fuel cell vehicles (FCVs) and combustion engines adapted for carbon-neutral fuels. At the same time, the company emphasizes the importance of developing a supporting service ecosystem to enable the practical implementation of these technologies [43].

As a part of its supporting service systems, Isuzu introduced its 'total solution program', EVision, in 2023 alongside the market launch of its first mass produced BEV. EVision is a designed to support customers in the transition to BEVs by helping them evaluate implementation, identify operational challenges, and develop solutions related to charging, and energy management. Through this, Isuzu aims to reduce barriers to electrification [43].

Circular Economy

The implementation of circular material flows is particularly evident in Isuzu's initiatives related to remanufacturing and rebuilding. A central element in this work is the extension of product and component lifetimes through the reuse and restoration of engines, transmissions and other major parts. In addition, Isuzu has developed PREISM, an advanced maintenance service based on vehicle data transmission. By continuously monitoring vehicle condition, PREISM enables preventative and predictive maintenance based on actual usage rather than fixed service time intervals, which can contribute to prolonged vehicle use and more efficient utilization of components [44].

4.1.5 Traton

MAN, Scania and International are all part of Traton, see figure 4.2. Although the companies operate as separate brands with distinct markets, product portfolios and strategic priorities, certain similarities can be understood in relation to their shared corporate ownership and organisational context.

Figure 4.2: Logotypes of brands included in Traton [45]

4.1.5.1 MAN

Sustainability Strategy and Governance

MAN's sustainability targets are strongly aligned with global climate frameworks and regulatory developments, but are also driven by a strategic ambition to transform the company into a provider of sustainable transport solutions. Sustainability is integrated as a core element of MAN's corporate strategy, reflecting the company's view that long term competitiveness depends on the ability to deliver low emission and resource efficient transport solutions [46].

To structure its sustainability efforts, MAN organises its strategy around six main action fields: decarbonisation, circular economy, people sustainability, road and product safety, compliance and ethics, and responsibility along the value chain. The three first are prioritised. These action fields are continuously reviewed and updated through internal analyses and stakeholder engagement processes. A materiality analysis and stakeholder engagement is conducted to identify the most relevant sustainability topics based on both business impact and stakeholder expectations, ensuring that strategic priorities remain aligned with external requirements and long term trends [46].

To ensure that sustainability targets are implemented across the organisation, MAN has established a multi level governance structure. Sustainability is coordinated through an interdisciplinary team representing all major business functions, while strategic decisions and performance monitoring are handled by the MAN Sustainability Board, chaired by the CEO. This structure enables integration of sustainability into both operational processes and long term strategic planning [46].

Sustainability Targets

A central objective for MAN is achieving greenhouse gas neutrality across its entire value chain by 2050 at the latest. This target is aligned with the Science Based Targets initiative (SBTi) and the Paris Climate Agreement. As intermediate targets, MAN aims to reduce greenhouse gas emissions from its operations (Scope 1 and 2) by 70% by 2030 compared to 2019 levels, and to reduce emissions per vehicle kilometer from sold products (Scope 3) by 28% within the same timeframe [46].

Decarbonisation is primarily addressed through the transformation of the product portfolio. Since the use phase of vehicles accounts for more than 96% of total emissions, MAN focuses heavily on electrification. The company is investing in battery electric trucks, buses, and vans, with the ambition that by 2030 up to 50% of new trucks sold in Europe will be battery electric. In addition to battery electric solutions, MAN is also exploring hydrogen based technologies as complementary solutions for specific applications [46].

Beyond product development, MAN also targets emissions within its production system. The company aims to achieve CO_2-neutral production by 2030 by reducing emissions by at least 95% compared to 2015 levels, with the remaining emissions offset. This is supported by investments in renewable energy, energy efficiency measures, and the implementation of certified energy management systems across production sites [46].

Technological Pathways

As part of its technological strategy, MAN is also exploring hydrogen-based technologies as a complementary pathway to decarbonisation. Primarily within its MAN Engines division for non-road applications such as maritime transport, agriculture and power generation. Hydrogen fuel cell systems are developed as an extension of battery electric vehicle platforms, where hydrogen is used for onboard energy generation. This enables a reduction in battery size, making the solution more suitable for applications requiring longer range and higher flexibility [46].

In addition to non-road applications, hydrogen-based technologies are also being considered for heavy truck road transport, where high energy demand and long operating ranges pose challenges for battery electric solutions. As part of this development, MAN plans to introduce a limited series of hydrogen-powered trucks (MAN hTGX) to pilot customers starting from 2025, supporting the transition toward zero-emission vehicle technologies [46].

In addition, MAN is investing in the development of charging infrastructure and energy systems required to support electrification. Through collaborations such as the Milence joint venture, the company is contributing to the expansion of high-performance charging networks for heavy trucks, which is a critical enabler for large-scale adoption of electric trucks [46].

Circular Economy and Lifecycle Optimisation

From a technological perspective, MAN is implementing several solutions to achieve its sustainability goals. They have initiated the development of a new generation of trucks designed with circular economy principles in mind. This includes improving the disassembly of components to facilitate material separation and recycling. The company also focuses on increasing the share of recycled materials, particularly plastics, as well as establishing requirements for battery production aligned with circularity. In the long term, MAN aims to enable closed-loop systems for battery materials such as nickel, manganese, cobalt and lithium, allowing recovered materials to be reused in new battery production [46].

MAN also applies digital solutions to improve resource efficiency throughout the vehicle life cycle. Through its predictive maintenance system, MAN ServiceCare, vehicle data is continuously monitored to identify maintenance needs and replace components at the optimal time. While not directly a waste management measure, this approach can extend components lifetimes and reduce unnecessary part replacements, indirectly contributing to lower material waste [46].

Another key technological implementation is the increasing digitalization of MAN's vehicle fleet. The company leverages connected vehicle systems and data-driven services to improve operational efficiency and reduce environmental impact. Through advanced telematics and digital platforms such as MAN Perform, real-time operational data is collected and analysed to optimise driving behavior, reduce fuel consumption and lower CO_2 emissions [46].

The integration of connectivity and digital services also enables predictive maintenance solutions, where vehicles are continuously monitored to detect wear and anticipate service needs. This reduces unnecessary maintenance, minimizes downtime and extends component lifetimes, contributing to improved resource efficiency across the vehicle life cycle [46].

4.1.5.2 Scania

Materiality Assessment

Scania applies a double materiality assessment (DMA) to identify, assess, and prioritise key sustainability issues. The DMA process is integrated into the company's broader risk management and strategic planning processes and is reviewed annually to reflect changing external and internal conditions. Sustainability-related risks are categorised into transition risks, such as regulatory and technological developments, and physical risks associated with climate change [47].

Sustainability Strategy and Targets

Scania has set a target of becoming fossil-free by 2050, in alignment with the Paris Agreement. This ambition is operationalised through shorter strategic planning cycles focusing on continuous decarbonisation across the value chain. In addition, the company has established an interim target for 2030, aiming to achieve 100 percent green procurement of key materials in its European operations, including steel, aluminium, batteries, and cast iron. The environmental scope further includes water use, waste management, chemical use, energy consumption, and biodiversity impacts [47].

Sustainability governance is integrated into the organisational structure, with responsibility assigned to top management. The Sustainability Board oversees sustainability-related issues, including target setting and cross-functional implementation [47].

Stakeholder engagement is an integral part of the sustainability approach and includes customers, employees, suppliers, and societal actors. This informs both strategic decision-making and the DMA process, with attention to rights holders and just transition considerations [47].

Scope 1, 2 and 3

Scania reports greenhouse gas emissions in accordance with the GHG Protocol and applies a well-to-wheel perspective for vehicle use. This enables full-chain emissions accounting, particularly for Scope 3 emissions [47].

Scope 1 and 2 emissions are addressed through renewable fuels and fossil-free electricity, largely via green electricity certificates. Scope 3 emissions represent the majority of total emissions, where electrification is identified as a key long-term solution [47].

Circular Economy and Life Cycle Optimisation

Circular economy principles are integrated into the business model through modular design, remanufacturing, reuse, and refurbishment. Service-based models are also applied, including ProDriver and the JUNA joint venture with sennder, enabling pay-per-use electric truck operations [47], [48].

The company implements energy efficiency measures in production and transport, including drivetrain improvements, renewable fuels such as HVO and biomethane, LED lighting, heat pumps, and waste management systems. According to Respondent 2, investment decisions are partly based on cost-efficiency metrics such as cost per unit of CO_2.

Supplier sustainability is ensured through environmental and social requirements, procurement criteria, and an internal sustainability rating system (S-rating) integrated into sourcing decisions [47].

4.1.5.3 International

Sustainability Strategy and Emissions Focus

International's environmental strategy is mainly centered around decarbonisation, circular business practices and operational environmental performance. The company identifies Scope 3 emissions as the largest source of its climate impact, with the use of sold products accounting for 96% of its total Scope 3 emissions. The company therefore states that customer adoption of low- and zero-emission vehicles is central to the company's sustainability work. In its sustainability reporting, International also states that its climate targets are intended to include Scope 1, Scope 2 and relevant Scope 3 emissions and that these targets are to be developed in line with the Science Based Targets initiative [49], [50].

Decarbonisation and Product Strategy

A central part of International's decarbonisation strategy is the development of battery electric commercial vehicles. The company offers the eMV Series, a medium-duty electric truck intended for urban and regional applications. International also provides support related to route analysis, charging planning and fleet electrification. These services are presented as part of the company's work to support customers in the transition to electric commercial vehicles [50].

International has also introduced the eRH Series, an all-electric Class 8 truck, in 2025. The eRH Series is designed for regional-haul and drayage operations and is offered in 4x2 and 6x4 axle configurations. According to International, the vehicle can achieve a range of up to 300 miles, depending on configuration, battery capacity and use [51].

International does not rely exclusively on electrification, but also continues to develop more efficient conventional powertrain technologies.

A central example is the International S13 Integrated Powertrain, which combines the S13 engine, the T14 transmission and a Dual Stage Aftertreatment system. According to International, this powertrain is intended to support the company's product strategy during the transition toward zero-emission transport solutions. The system has been developed to improve fuel efficiency and reduce greenhouse gas emissions through higher combustion efficiency, reduced internal losses and improved exhaust aftertreatment. The S13 engine uses selective catalytic reduction as its main emissions-reduction technology, while the T14 transmission includes integrated software controls and driving modes adapted for different truck applications. In this way, International presents the S13 Integrated Powertrain as part of a transitional approach where battery electric vehicles are developed alongside improvements in combustion-based transport solutions [49].

Circular Economy and Resource Use

Circularity is another important part of International's sustainability approach. The company highlights remanufacturing as a way to extend the lifetime of products and components, reduce demand for new raw materials and support a more circular business model. International states that it sells and distributes approximately 3,000 remanufactured parts annually, and that four central facilities collect and refurbish parts to support circularity. The company has also set a goal for remanufactured parts to account for 20% of parts revenue [50].

4.2 Integration of Sustainability Goals in Product Development and Business Models

Overall, the companies integrate sustainability into product development and business models as a long-term strategy, with the Paris Agreement serving as a key reference framework. Sustainability governance is integrated to varying degrees through dedicated governance structures, sustainability boards, cross-functional collaboration and materiality assessments used to prioritise relevant sustainability issues based on organisational impact and stakeholder expectations.

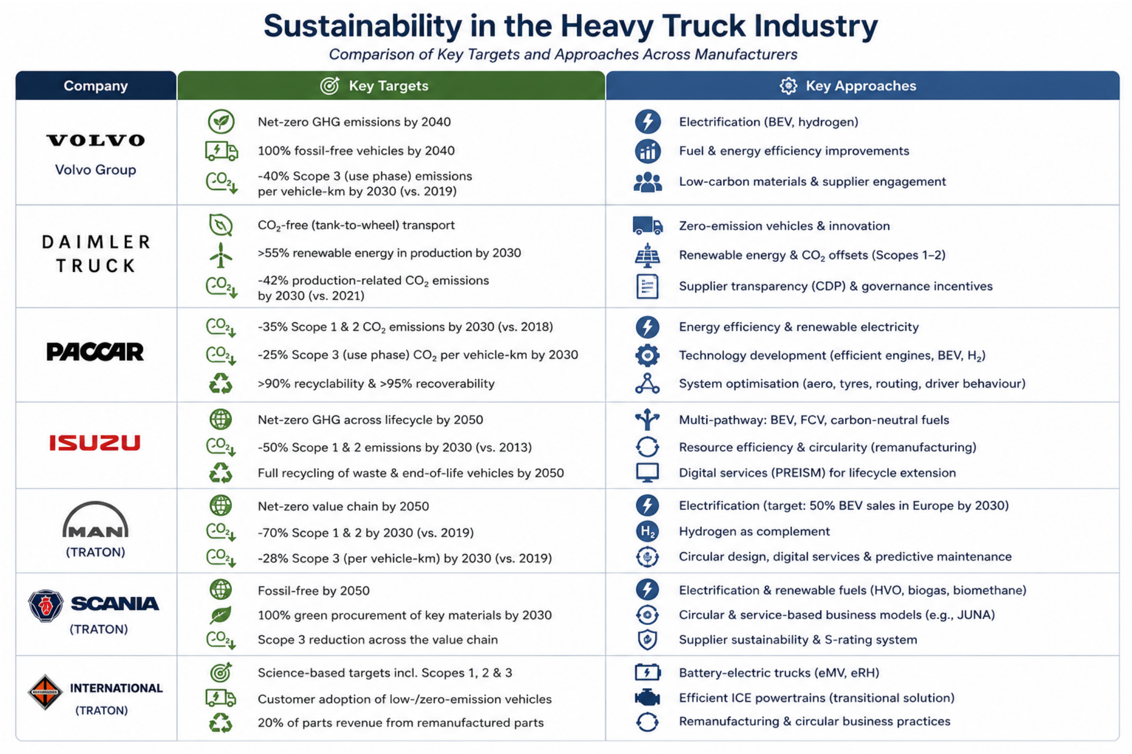
A central finding is that decarbonisation is the most critical sustainability objective across all companies, driven particularly by the need to address Scope 3 emissions due to their significant share of total climate impact. This prioritisation reflects a broader strategic shift in which sustainability increasingly extended to customers and downstream product use, where the largest emission reduction potential is located.

In addition, several companies explicitly integrate lifecycle thinking into both product development and investment decisions. This includes not only emissions over the full vehicle life cycle, but also broader considerations such as material use, end-of-life treatment, and resource efficiency. Life cycle-based economic evaluation is reflected in decision criteria such as cost per CO_2 abated, which illustrates how traditional financial models are increasingly combined with environmental performance indicators.

Across the companies, there is a clear emphasis on extending the value of products and materials over time and reducing dependency on virgin resources. Circular economy principles are primarily framed at a strategic level as an approach to improving resource efficiency and system resilience rather than as isolated operational measures.

Digitalization is identified as an enabler of sustainability integration, supporting both improved coordination of sustainability efforts and the development of service-based business models. This includes a shift toward more usage-oriented and life cycle-focused offerings, which in turn enables new approaches to reducing downstream emissions.

Overall, the findings indicate that sustainability is no longer treated as a separate initiative, but has become embedded in the core of corporate strategy, where climate targets, circular business models and life cycle perspectives together are reshaping both product development and business logic toward long-term systemic change.



Sustainability in the Heavy Truck Industry

Comparison of Key Targets and Approaches Across Manufacturers

Company	Key Targets	Key Approaches
VOLVO Volvo Group	Net-zero GHG emissions by 2040 100% fossil-free vehicles by 2040 -40% Scope 3 (use phase) emissions per vehicle-km by 2030 (vs. 2019)	Electrification (BEV, hydrogen) Fuel & energy efficiency improvements Low-carbon materials & supplier engagement
DAIMLER TRUCK	CO_2-free (tank-to-wheel) transport >55% renewable energy in production by 2030 -42% production-related CO_2 emissions by 2030 (vs. 2021)	Zero-emission vehicles & innovation Renewable energy & CO_2 offsets (Scopes 1–2) Supplier transparency (CDP) & governance incentives
PACCAR	-35% Scope 1 & 2 CO_2 emissions by 2030 (vs. 2018) -25% Scope 3 (use phase) CO_2 per vehicle-km by 2030 >90% recyclability & >95% recoverability	Energy efficiency & renewable electricity Technology development (efficient engines, BEV, H_2) System optimisation (aero, tyres, routing, driver behaviour)
ISUZU	Net-zero GHG across lifecycle by 2050 -50% Scope 1 & 2 emissions by 2030 (vs. 2013) Full recycling of waste & end-of-life vehicles by 2050	Multi-pathway: BEV, FCV, carbon-neutral fuels Resource efficiency & circularity (remanufacturing) Digital services (PREISM) for lifecycle extension
MAN (TRATON)	Net-zero value chain by 2050 -70% Scope 1 & 2 by 2030 (vs. 2019) -28% Scope 3 (per vehicle-km) by 2030 (vs. 2019)	Electrification (target: 50% BEV sales in Europe by 2030) Hydrogen as complement Circular design, digital services & predictive maintenance
SCANIA (TRATON)	Fossil-free by 2050 100% green procurement of key materials by 2030 Scope 3 reduction across the value chain	Electrification & renewable fuels (HVO, biogas, biomethane) Circular & service-based business models (e.g., JUNA) Supplier sustainability & S-rating system
INTERNATIONAL (TRATON)	Science-based targets incl. Scopes 1, 2 & 3 Customer adoption of low-/zero-emission vehicles 20% of parts revenue from remanufactured parts	Battery-electric trucks (eMV, eRH) Efficient ICE powertrains (transitional solution) Remanufacturing & circular business practices

Figure 4.3: Summary of companies key-targets and approaches. (Created with ChatGPT, 2026)

4.3 Benchmarking of Sustainability Performance

This section presents the benchmarking results for product & supply chain performance as well as operational sustainability performance. Detailed calculations for the metric values and resulting scores are provided in Appendix B.1 and Appendix C.1, where the calculations are organised by company.

The benchmark for product and supply chain performance is presented in table 4.1. The table includes the selected metrics, their assigned weights and the score achieved by each OEM. Scope 3 emissions were assigned the highest weight, 55%, since emissions from the use phase represent the dominant share of life cycle emissions in the industry. Total energy consumption was assigned the second highest weight, 35%, as truck manufacturing is energy intensive. The remaining metrics, substances of concern and particulate matter from tire wear, were assigned lower weights due to limited data availability and lower comparability across companies, see table 4.1.

The results show that Isuzu achieves the highest total score, 4.75, meaning that it performs best according to the selected sustainability criteria. PACCAR follows with 3.80, while International receives 3.60 and Daimler receives 3.35. Volvo Group scores 2.85 and MAN scores 2.65, placing them in the lower part of the comparison. Scania receives the lowest total score, with 1.45, see table 4.1

Since Scope 3 emissions and Total Energy Consumption together account for 90% of the total weighting, performance in these categories had the greatest influence on the final result. Isuzu's strong performance is mainly explained by its high scores in both Scope 3 Emissions and Total Energy Consumption. In contrast, Scania's low score is largely due to its weak performance in these heavily weighted categories.

Table 4.1: Benchmark of product and supply chain sustainability metrics.

Metrics	Weight	PACCAR	Internationa	Volvo Group	Daimler	Isuzu	MAN	Scania
Region of Production		North America	North America	North America	Global	Global	Europe	Europe, Latin America, Asia
Product & Supply Chain								
Scope 3 Emissions	55%	4	3	3	3	5	2	1
Total Energy Consumption	35%	4	5	3	4	5	4	2
Particulate Matter in Tire Wear	5%	1	1	1	1	1	1	1
Substances of Concern	5%	3	3	2	5	4	2	3
Total Score		3,80	3,60	2,85	3,35	4,75	2,65	1,45

The benchmark for operational sustainability performance is presented in table 4.2. This part of the benchmark evaluates the companies own operations using metrics related to waste, Scope 1 and Scope 2 emissions, renewable energy use and fresh water consumption. The metrics were assigned similar weights because they are all considered equally relevant, see table 4.2.

The results show that International achieved the highest total score, 4.10, meaning that it performs best according to the selected operational sustainability criteria. Scania follows with 3.74, while Volvo Group receives 3.16. MAN scores 3.70, Isuzu scores 2.70 and Daimler scores 2.64. PACCAR receives the lowest total score, 2.16, see table 4.2.

Since Non-Recycled Non-Hazardous Waste, Non-Recycled Hazardous Waste, Scope 1 Emissions, Scope 2 Emissions and Renewable Energy Use all have a weighting of 18%, performance in these categories have the highest influence on the final result. International's strong result is mainly explained by its high performance in Non-Recycled Hazardous Waste, Scope 1 Emissions, and Fresh Water Consumption. PACCAR's low score is largely due to weak performance in several of the more heavily weighted waste and emissions categories, see table 4.2.

Table 4.2: Benchmark of operational sustainability metrics

Metrics	Weight	PACCAR	International	Volvo Group	Daimler	Isuzu	MAN	Scania
Region of Operation		North America	North America	North America	Global	Global	Europe	Europe, Latin America, Asia
Operations								
Non-Recycled Non-Hazardous Waste	18%	1	3	5	5	5	5	4
Non-Recycled Hazardous Waste	18%	1	5	3	3	1	5	3
Scope 1 Emissions	18%	4	5	2	2	4	2	3
Scope 2 Emissions	18%	4	4	4	1	3	5	4
Renewable Energy Use	18%	2	3	3	2	2	3	4
Fresh Water Consumption	10%	1	5	1	3	4	1	5
Total Score		2,16	4,10	3,16	2,64	2,70	3,70	3,74

4.4 Technological Solutions for Sustainability Improvement

Sustainability Improvement examines Scope 3 emissions, total energy consumption and waste, as these are important sustainability metrics with significant environmental impact and areas where Volvo Group has potential to improve. The 9R framework was used as a guiding tool when identifying operational practices, and the measures identified in the analysis were mainly connected to *Rethink*, *Repair* and *Reduce*.

4.4.1 Scope 3

Business Model

One way to reduce Scope 3 emissions is through the adoption of electric trucks, since a large share of these emissions is connected to the use phase of sold vehicles. However, electric trucks also create new challenges for customers, such as high investment costs, charging infrastructure, route planning and uncertainty about daily operations. Therefore, *rethinking* the business models can be an important tool for lowering these barriers and making electric trucks easier to adopt in practice.

A relevant example is Isuzu, which received a stronger score in Scope 3. Isuzu has developed EVision, a "total solution program" designed to support customers in the transition to battery electric commercial vehicles. The program reduces practical barriers by offering route analysis, charging planning, cost calculations, implementation support and follow-up of environmental performance. This is important because the challenge is not only to produce electric trucks, but also to make customers more willing and able to adopt them. By reducing uncertainty related to charging infrastructure, daily operations and total cost of ownership (TCO), EVision can increase customer confidence and make electric trucks a more attractive alternative [52].

Scania has also worked to make the adoption of electric trucks easier through its joint venture JUNA. Although Scania did not score particularly well in the Scope 3 metric, JUNA is still relevant to analyse because it illustrates how truck manufacturers can support customer adoption beyond direct sustainability reporting figures. JUNA is based on a Truck-as-a-Service model, where customers access electric trucks through a pay-per-use structure. This lowers the investment barrier, since carriers do not need to bear the full upfront cost of purchasing electric trucks [48].

Previous research further supports the relevance of this business model. Gillström [31] identify two key barriers to electric truck adoption: high initial investment cost and uncertainty regarding vehicle utilisation. The higher purchase cost makes investment difficult in a low-margin logistics industry, while limited range, charging time, route planning and insufficient charging infrastructure may reduce operational efficiency. This shows that electrification requires business models that reduce both financial risk and uncertainty in daily use.

Truck-as-a-Service is therefore a relevant business model because it directly addresses the financial barrier. This can be seen both in JUNA's model and in Volvo On Demand, where customers can access Volvo electric trucks through a usage-based model rather than through traditional ownership [53].

However, JUNA's model goes further because it also addresses the second barrier: the practical use of electric trucks in daily operations. Through Sennder's digital freight platform, JUNA can connect carriers with a large network of shippers while also planning routes where both transport demand and charging infrastructure are available. As a result, customers are not only given access to electric trucks, but also better conditions to use them efficiently, with higher utilization and lower operational risk. In this way, electrification becomes part of an integrated logistics solution rather than only a vehicle investment [48].

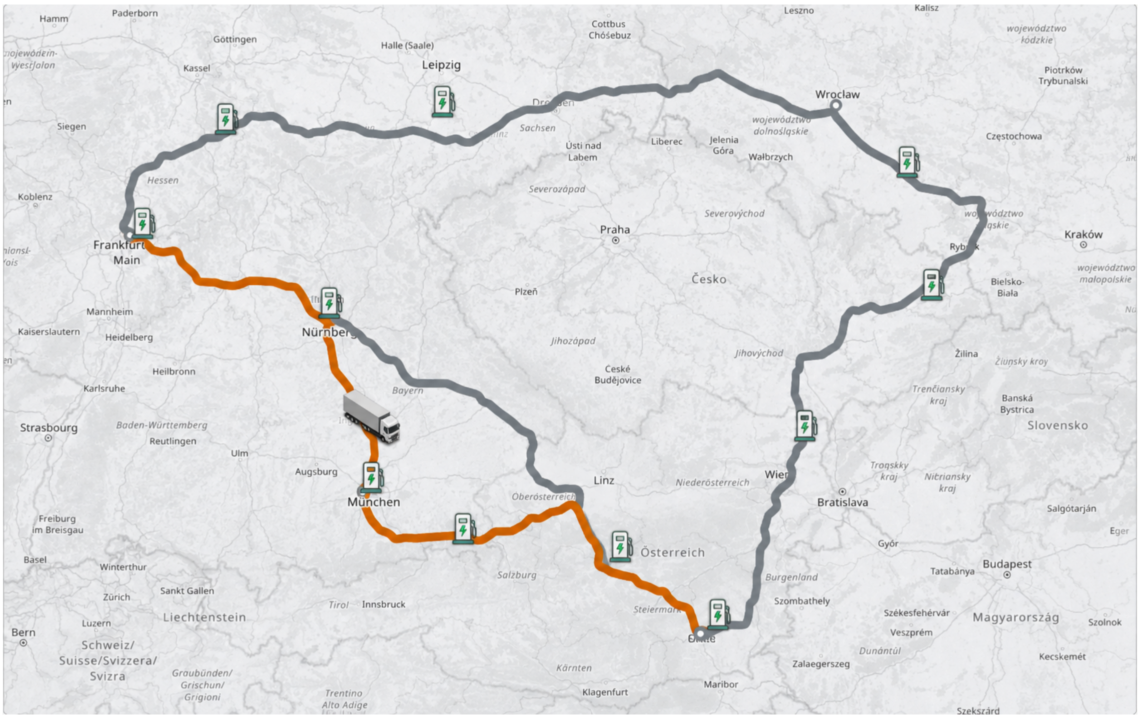


Figure 4.4: Illustration of an electric truck route with charging stations along the transport route. (Created with ChatGPT, 2026).

Based on this analysis, a practical recommendation is that Volvo Group should further develop Volvo On Demand by adding a stronger operational platform for route optimisation, charging planning and utilization support, similar to the role Sennder plays in JUNA. This would be especially relevant in North America, where charging infrastructure for electric heavy trucks remains a major limitation. By partnering with a company that has a strong shipper network, freight-flow data and knowledge of charging infrastructure, Volvo Group could reduce customer uncertainty regarding both cost and operational feasibility. This would strengthen Volvo On Demand from being mainly a financing or leasing-like solution into a more complete electrification offering. In the long term, such a development could also accelerate the transition to zero-emission transport and thereby contribute to reducing Volvo Group's Scope 3 emissions.

Predictive Maintenance

An additional approach for reducing Scope 3 emissions in the heavy truck industry is to *repair* the trucks by increasing the use of predictive maintenance enabled by connected vehicle data. It is a tool that directly influences emissions which are generated after the point of sales.

Predictive maintenance systems use connected vehicle data to identify operational inefficiencies and maintenance-related issues that may increase fuel consumption or emissions. These could include aftertreatment problems, inefficient engine operation, underinflated tires or battery degradation. By alerting fleets early and encouraging proactive maintenance, predictive maintenance enables customers to operate their vehicles more efficiently while reducing emissions during the vehicle's use phase. Since use-phase emissions are closely linked to fuel consumption, these systems have the potential to contribute to measurable reductions in Scope 3 emissions.

Volvo Group already has much of the technological foundation required for predictive maintenance in place. The company uses AI-supported connected services to dynamically adjust maintenance intervals based on real-time operational data replacing traditional static service schedules with condition-based maintenance. Combined with approximately one million connected trucks globally and a 24/7 Uptime Center, Volvo Group has an extensive connected service infrastructure in place [54]. However, a benchmarking analysis against competitors reveals gaps that currently limit the effectiveness of Volvo Group's predictive maintenance strategy as a measurable Scope 3 reduction tool

The first gap concerns the depth of predictive capability. Scania's Services 360 Pro uses AI-powered analysis of data from connected vehicles to predict probable future failure points for each individual vehicle and proactively replaces critical powertrain components before issues arise [55]. Volvo Group's Blue Service Contract uses proprietary AI models to optimise service intervals based on real-time data [56]. While both systems use AI and connected vehicle data, the distinction is meaningful: degrading powertrain components such as turbochargers and exhaust systems increase fuel consumption before a fault code is ever triggered, meaning interval optimisation alone cannot capture these efficiency losses. Component-level failure prediction may address efficiency losses more directly by enabling replacement before degradation affects operational performance. Since the use phase accounts for approximately 95 percent of Volvo Group's total life cycle emissions [38], this gap has a direct bearing on Scope 3 emission reductions.

A second identified gap is Volvo Group's lack of collaboration with specialised predictive analytics providers. Daimler has partnered with Uptake, a predictive analytics Software-as-a-Service provider, giving its customers access to data-driven failure predictions generated by 65 data science models trained on large-scale fleet data [57]. Such partnerships suggest that specialised analytics providers, with models trained across diverse vehicle populations and operational environments may complement an OEM's internal capabilities in ways that accelerate predictive accuracy. Volvo Group currently communicates no comparable partnership specifically focused on predictive failure analytics.

Based on this analysis, one main recommendation emerges. Volvo Group should further develop its predictive maintenance capability toward component-specific failure prediction, potentially through partnerships with specialised analytics providers. The technological infrastructure and connected fleet data already exist, the primary challenge is for Volvo Group to more fully utilize this data to enable component-specific failure prediction.

4.4.2 Total Energy Consumption

Total energy consumption is another important metric in the production phase and based on the benchmark, Isuzu and International appear to be two companies that have had the most success *reducing* energy consumption in their production operations. However, their publicly available information is relatively general, which means the analysis should focus on their overall approach rather than specific production solutions.

Isuzu states that the company works with energy efficiency through process improvements, optimised equipment operation and visualization of energy consumption. This means that the company attempts to identify where energy is used and then reduce unnecessary consumption through better control and more efficient processes [43].

International includes energy use as part of its sustainability work and monitors environmental data related to energy, water, waste and emissions. The company also mentions reductions in electricity, natural gas and energy use at different facilities. However, the information is not detailed regarding exactly which production processes have been changed. Therefore, International should mainly be viewed as an example of energy management at the facility level [58].

Daimler Truck is also relevant to analyse, since the company also scored well and presents a more concrete process improvement linked to energy use in production. Daimler states that painting is the largest single energy consumer in production at the Mercedes-Benz plant in Wörth am Rhein. This makes the paint shop a particularly important area to study when Volvo Group aims to reduce its total energy consumption [59].

A central measure introduced by Daimler is the wet-on-wet process for painting truck cabs. In a traditional painting process, one paint layer is often applied and then dried before the next layer can be added. This requires a significant amount of energy because drying ovens are used several times. In Daimler's new process, paint materials with a high solids content are used, making it possible to apply several paint layers directly after one another without drying between each layer. After primer application the following layers can be applied in the same paint booth [59].

The advantage of the wet-on-wet process is that the truck cab needs to pass through energy-intensive drying ovens fewer times. Daimler states that the new process requires fewer painting stations and fewer dryers, which reduces both energy use and resource consumption. According to Daimler, energy use in the paint shop can be reduced by up to 40% [59].

Based on this, Volvo Group should evaluate whether a similar wet-on-wet process could be implemented in its own production. Isuzu and International show that systematic monitoring, process optimisation and improved equipment control are important general approaches. Daimler, however, provides a more concrete example of how a specific energy-intensive process can be fundamentally changed. Since painting is a major energy consumer in truck production, Volvo Group should prioritise analysing the painting process, especially the number of drying stages and oven cycles. The conclusion is therefore that Volvo Group should investigate wet-on-wet as a possible measure to reduce energy use in the paint shop and thereby lower total energy consumption in production.

4.4.3 Waste

Waste generation and the handling of hazardous substances are important sustainability challenges within truck manufacturing, particularly in paint shop operations where solvents, chemicals, and coating materials are extensively used. In the benchmark analysis, Volvo Group performs relatively weak in metrics related to hazardous waste and substances of concern, indicating potential for *reducing* chemical-intensive production processes.

A relevant benchmark example is Daimler Truck, which has implemented a wet-on-wet painting process in parts of its truck production [59]. Instead of drying each paint layer separately, multiple paint layers are applied consecutively before entering drying. This reduces the amount of painting material needed, while also decreasing the use of solvents and other hazardous chemicals during the painting process.

As a result, the wet-on-wet process contributes to lower volumes of hazardous waste and reduced emissions of volatile organic compounds [60]. Based on this analysis, Volvo Group should evaluate whether similar painting technologies could be implemented within its own production system as a way to reduce hazardous waste generation.

4.5 The Impact of Geopolitics and Sustainability Regulations on Future Strategic Development

The framework describes four possible future scenarios for the heavy truck industry based on two critical uncertainties related to support for the energy transition and geopolitical relations between China and the Western world. The scenarios illustrate how external geopolitical and regulatory developments may shape future market conditions and strategic priorities within the industry.

4.5.1 Drivers for the Heavy Truck Industry

The trucking industry is undergoing a major transformation driven by increasing sustainability requirements, technological development and shifting global trade patterns. At the same time, the industry is characterized by significant uncertainty, which makes long-term planning complex. The key drivers for the heavy-truck sector is presented using the STEEP framework, see figure 4.5. Growing climate awareness and corporate sustainability commitments increase demand for low-emissions transport solutions, while technological progress in Alternative Fuel Vehicles (AFVs) expands the range of viable drivetrain options.

At the same time, volatile raw-material markets, fragile global supply chains and fluctuating transport demand, introduce economic uncertainty. Environmental pressure to reduce GHG emissions intensifies the need for large-scale electrification, which in turn depends on access to renewable energy and charging infrastructure.

Finally, regulatory developments and geopolitical tensions shape market conditions, supply chain resilience and the pace of the transition toward fossil-free transport.

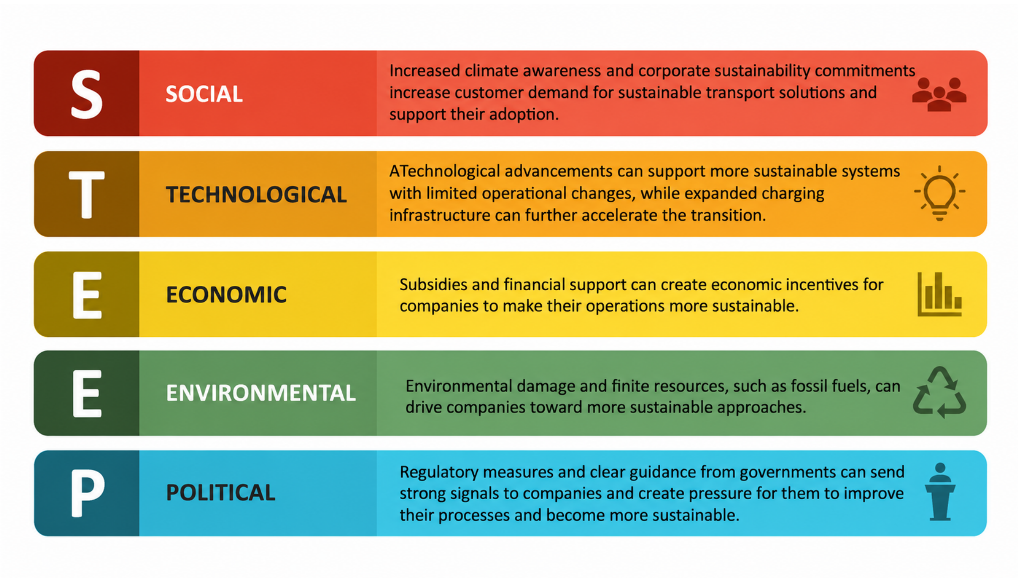


Figure 4.5: STEEP-framework for external factors shaping the heavy-truck sector.

4.5.2 Uncertainties for the Heavy Truck Industry

Based on the identified drivers, a number of key uncertainties for the heavy truck industry can be derived, particularly in areas where future developments are difficult to predict.

A central uncertainty is the development and credibility of regulatory requirements related to sustainability. Stricter emission regulations and policy initiatives are accelerating the transition toward fossil-free transport by shaping the conditions under which firms evaluate long-term investments in electrification and alternative drivetrains. This argument is supported by Rogge and Dütschke [29], who argue that firms willingness to invest in low-carbon transitions depends on whether the policy mix is perceived as credible, coherent and consistent over time.

Another key uncertainty is the geopolitical situation, which has a major impact on global supply chains and trade flows. Previous research on geopolitical disruptions shows that political tensions, trade barriers and supply disruptions influence supply chain management decisions and increase the need for resilience, diversification and reduced dependency on vulnerable external actors [30]. This is of particular relevance to the trucking industry, which remains highly dependent on international supply chains for components, raw materials and production.

4.5.3 Potential Scenarios

By combining these uncertainties along two axes, four different future scenarios are formed, see figure 4.6. Within each scenario there are both opportunities and risks that affect the heavy truck industry. These can have an impact both at an overall strategic level, but also on how investments and implementations in sustainability should be carried out.

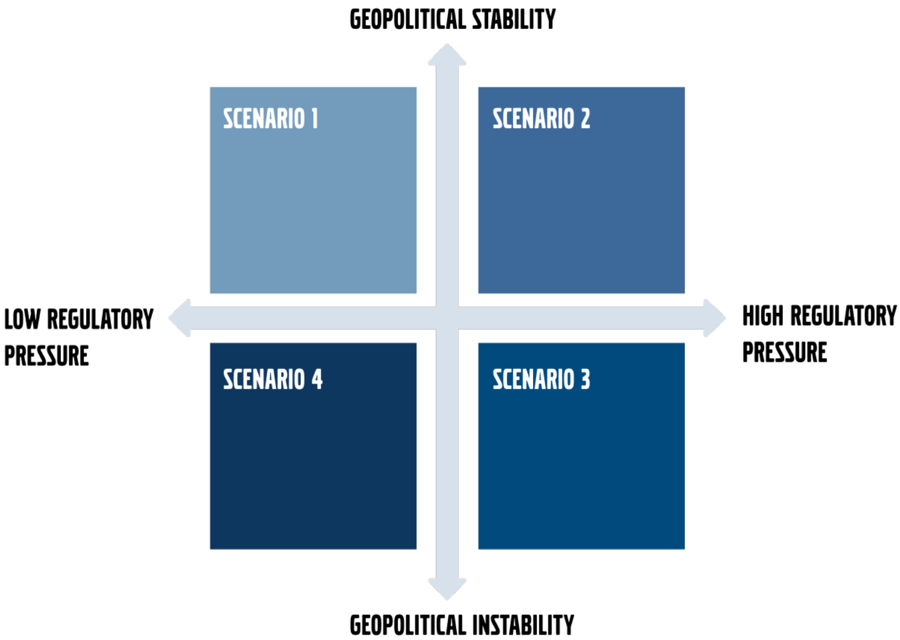


Figure 4.6: Potential scenarios regarding Geopolitical stability and level of regulations

4.5.3.1 Scenario 1: Low regulatory pressure & Geopolitical stability

In this scenario, weak regulatory pressure reduces the urgency to shift rapidly toward battery electric heavy trucks. OEMs are therefore likely to prioritise incremental improvements in existing diesel-based platforms and production systems, such as fuel efficiency, engine performance, aerodynamics, manufacturing energy use and material efficiency. Sustainability progress would still occur, but mainly through optimisation rather than a radical technology shift.

Stable geopolitical conditions allow firms to use global supply chains with relatively low disruption risk. This creates room for cost-efficient outsourcing of large parts of production, especially components and processes that are not strategically critical.

Overall, this scenario favours a gradual and cost-oriented strategy. OEMs can focus on efficiency, profitability and global production optimisation while continuing to build selected capabilities for a possible future electrification shift.

4.5.3.2 Scenario 2: High regulatory pressure & Geopolitical stability

In this scenario, strong regulatory pressure accelerates the transition toward battery electric heavy trucks. Stricter emission requirements and policy incentives make diesel-based strategies less viable over time, leading OEMs to prioritise BEV development, battery integration, charging-related solutions and electric drivetrain competence.

Because geopolitical conditions are stable, firms can still rely on international suppliers and outsource non-critical parts of production where this improves cost efficiency or flexibility. However, battery-related activities are likely to remain closely controlled, as batteries are central to vehicle performance, cost structure and long-term technological advantage.

The main strategic outcome is a fast but globally integrated transition. OEMs that can scale BEV technology while using international production networks efficiently are likely to be well positioned in this scenario.

4.5.3.3 Scenario 3: High regulatory pressure & Geopolitical instability

In this scenario, OEMs face simultaneous pressure to electrify and reduce supply chain vulnerability. Strong regulation pushes the industry toward battery electric heavy trucks, making BEV development, battery competence and electric drivetrain integration central strategic priorities.

At the same time, geopolitical instability makes broad outsourcing risky. Firms are likely to keep battery-related activities under close control and reduce dependence on external suppliers for other strategically important parts of production. This may increase the need for regional production, supplier diversification, vertical integration and secure access to critical materials.

This scenario is the most demanding. OEMs must invest heavily in electrification while also building resilient and controlled supply chains. Competitive advantage is likely to depend on financial strength, technological capability and the ability to scale BEVs without becoming overly dependent on vulnerable global suppliers.

4.5.3.4 Scenario 4: Low regulatory pressure & Geopolitical instability

In this scenario, limited regulatory pressure allows OEMs to continue focusing on diesel-based vehicles and existing production systems. The main emphasis is likely to be on improving fuel efficiency, reducing operational emissions, lowering production costs and extending the competitiveness of current vehicle platforms.

However, geopolitical instability changes the supply chain logic. Trade barriers, political tensions and disruption risks make outsourcing less attractive. Firms are therefore likely to prioritise regional sourcing, supplier diversification, internal manufacturing capacity and stronger control over the value chain.

The strategic response is defensive and resilience-oriented. Rather than pursuing rapid electrification, OEMs would focus on protecting operational continuity, reducing exposure to fragile global supply chains and improving existing technologies where possible.

4.5.4 Scenario Synthesis

To summarise the four scenarios, a cross-scenario comparison is presented to highlight the key differences in technological development, supply chain structure, and electrification pace. For a comparative overview of scenario characteristics, see table 4.3.

Table 4.3: Comparative overview of scenario characteristics

Aspect	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Electrification pace	Slow	Rapid	Rapid	Slow
Technology development	ICE	BEV	BEV	ICE
Supply chain structure	Globalised	Globalised	Regionalised	Regionalised

Volvo Group must operate in a future with high strategic uncertainty, mainly driven by changes in sustainability regulation and geopolitical conditions. These factors influence both the speed of electrification and the structure of global supply chains. In stable and globally connected scenarios, a cost-focused logic dominates, where efficiency and economies of scale are the main sources of competitiveness. In contrast, more uncertain and fragmented futures require a stronger focus on control, resilience, and regionalised value chains. In this context, strategic flexibility becomes a key capability for adapting to different technological and geographic developments.

The analysis shows that these factors strongly affect how value creation shifts between ICE and BEV technologies. In scenarios with low regulatory pressure and slow electrification, ICE solutions remain competitive. However, stricter regulation speeds up the transition towards BEVs and reduces the long-term importance of ICE investments. At the same time, geopolitical conditions determine whether global or regional supply chains are most efficient. Stable trade relations support cost-efficient global sourcing, while fragmentation increases the need for local production, redundancy, and greater control over critical components.

The role of electrification also depends on regulation and infrastructure development. This affects both the speed of transition and the ability to build a stable customer base for BEVs. In low-regulation scenarios, electrification develops slowly and is mainly driven by the market. In contrast, high regulation combined with infrastructure growth accelerates adoption and makes electrification a strategic requirement rather than an option.

Supply chain strategy is also shaped by geopolitical conditions. Stable environments support global cost optimisation through outsourcing and scale advantages. Fragmented conditions instead lead to regionalisation, dual sourcing, and more vertical integration of key components to reduce exposure to external shocks.

Across all scenarios, there is a clear shift towards more service-oriented business models. Digitalisation, such as fleet management, aftermarket services, and improved supply chain visibility, becomes an important competitive factor. Electrification follows a gradual development in all scenarios, meaning the transition is evolutionary rather than disruptive, even under more conservative conditions.

Overall, the scenarios show a dual strategic logic in the industry. Future competitiveness cannot rely only on cost efficiency or technological leadership, but must balance both. In stable scenarios, efficiency is the main focus, while uncertain and fragmented futures are defined by resilience, control, regionalisation, and technological independence.

Managing this uncertainty requires high strategic flexibility, both in drivetrain portfolio decisions and in supply chain design. A portfolio approach, where investments are spread across ICE, BEV, and other technologies, is necessary to ensure stability across different future outcomes. The main competitive advantage is therefore not a single technological choice, but organisational adaptability and the ability to reallocate resources when external conditions change.

A key enabler of this flexibility could be greater modularisation within the Volvo Group. While already partly in place, the analysis shows a need to further expand shared modular architectures across companies. This reduces system complexity and improves the ability to shift production and resources between regions as conditions change.

This is especially important in a geopolitically uncertain environment, where supply chain stability cannot be taken for granted and disruptions may require fast adjustments in sourcing and production. It also supports regulatory adaptability by enabling quicker transitions between powertrain technologies as emissions requirements evolve.

5 Discussion

The discussion is divided into three parts. First, the project assignment and scope are reflected upon. Second, the methodology and approach are discussed. Finally, the results are reflected upon.

5.1 Reflection on the Project Assignment

The given project assignment was to conduct a structured comparative analysis between Volvo Group and other leading OEMs. The deliverables consisted of a benchmarking system in the form of a scoring model, a gap and best practice analysis, and proposed recommendations for Volvo Group's future work. Consequently, the assignment had a broad scope, as it included methodological development, analysis of several companies, and the formulation of strategic recommendations.

The broad scope created challenges, since the assignment was initially relatively open. On the one hand, this gave the group freedom to define the direction of the analysis. On the other hand, it meant that considerable time had to be spent on defining the scope, delimiting the analysis, and deciding which sustainability areas should be prioritised. The work would likely have benefited from a more specified initial scope, for example through a clearer area of focus. One possible improvement could have been to focus only on the most critical metrics, such as Scope 3 emissions. This could have enabled a more in-depth and specific analysis.

5.2 Reflection on Methodology and Approach

A reflection regarding the overall bachelor thesis process is that the project involved several stakeholders with partly different expectations and priorities. The sponsor, Volvo Group, the collaborating students from Penn State, and the supervisors at Chalmers all contributed with different perspectives regarding the direction and focus of the project. At times, this made it challenging to determine how the work should be prioritised and structured in order to balance stakeholder expectations with the overall objectives of the study. As a result, a considerable amount of time was spent on coordination and project organisation rather than the research itself.

The collaboration with the students from Penn State functioned well overall. However, the projects were initiated at different points in time, which initially resulted in differences in understanding of the project scope and subject area. During the early stages of the collaboration, this occasionally created difficulties in maintaining alignment regarding objectives, knowledge level and contributions to the work process.

Regarding the interviews, the study would likely have benefited from a narrower and specialised scope. Since a broad range of sustainability metrics and operational aspects were included, the interviews tended to remain relatively general rather than providing deeper insights into specific areas. Consequently, the interviews primarily contributed with broad overviews of different topics instead of more detailed operational understanding. A more focused research scope could potentially have enabled more in-depth discussions and empirical findings.

Concerning the literature review and secondary data collection, the initial expectation was that a larger amount of open-source data would be available. However, access to detailed and comparable information was limited in several areas, which restricted the possibility of conducting deeper analysis within certain topics. In addition, much of the publicly available corporate information primarily highlights areas in which companies perform well, while weaknesses and challenges are often less transparent or insufficiently quantified. Since the study relied heavily on publicly available information, this may have introduced a bias toward positive sustainability initiatives and strengths, while making it more difficult to identify operational shortcomings or areas with weaker performance. This limitation may have affected the overall balance and objectivity of the comparative analysis.

5.3 Reflection on the Result

The results show that the studied heavy truck manufacturers have many similarities in their sustainability strategies, targets and reported initiatives. Most companies focus on decarbonisation, electrification, renewable energy, circularity and reductions in Scope 1, 2, and 3 emissions. This made it difficult to identify clear and substantial differences between them. The main differences were instead related to reporting detail, transparency and progress toward stated targets.

The benchmark identified several areas where Volvo Group appeared to underperform compared to competitors. However, these results should be interpreted with caution since the analysis relied largely on publicly available company reports. Differences in reporting methods, baseline years, definitions and level of transparency may have affected the comparison. It is therefore difficult to determine whether the results reflect actual performance differences or differences in how companies choose to report their sustainability work.

Another limitation is that several assumptions and estimations had to be made, as the companies did not report all indicators in the same way and may have included different parts of their operations in the reported figures. This may have influenced the final benchmark outcome. Therefore, the results should be seen as an indicative comparison rather than a definitive ranking.

The results would have been strengthened by more in-depth interviews with all companies included in the study. However, since most companies did not show interest in participating, the empirical basis was uneven. More interviews could have helped validate the findings and provided a deeper understanding of how sustainability strategies are implemented in practice.

Overall, the results provide a useful overview of Volvo Group's position in relation to competitors, but the findings should mainly be used as a basis for discussion and further investigation rather than as a complete assessment of sustainability performance.

6 Conclusions

This study examined how heavy truck OEMs integrate sustainability into their strategies, operations and technological development. Through benchmarking, best practice analysis and scenario analysis. The findings show that sustainability is no longer treated as a separate compliance activity, but is increasingly integrated into overall business strategies, product development and operational decision making.

Regarding the research questions:

- Which sustainability goals are integrated into product development and business models?
- Which sustainability goals are the most critical for achieving significant impact in the heavy truck industry?

The study shows that sustainability goals and targets are shaped by regulatory requirements and customer expectations linked to these regulations. Across all studied OEMs, the main focus areas are decarbonisation through electrification, energy efficiency and circularity. Among these, reducing Scope 3 emissions emerged as the most critical goal, since use-phase emissions constitute the largest share of lifecycle emissions. Consequently, OEMs increasingly focus on the development of AFVs, implementing predictive maintenance, and optimizing current diesel trucks.

Concerning the research questions:

- Which sustainability-related technologies, systems and operational practices can be identified among heavy truck manufacturers?
- Which technological or operational improvements should Volvo Group prioritise to strengthen its sustainability performance?

The analysis shows that OEMs increasingly use connected services, predictive maintenance, supplier rating systems and service-based business models to support sustainability integration. Circularity and material efficiency are also gaining strategic relevance, although implementation remains uneven across the industry. Based on the benchmarking and best practice analysis, Volvo Group should prioritise stronger integrated electrification services, more advanced predictive maintenance and operational improvements in energy-intensive production processes, particularly within paint shop operations

As for research questions:

- How can different combinations of regulatory support for sustainability and geopolitical developments shape future conditions in the heavy truck industry?
- How do these alternative future scenarios influence sustainability strategies, technology choices and supply chain configurations?

The scenario analysis shows that stronger sustainability regulations are likely to accelerate electrification, while geopolitical instability increases need for regionalised and resilient supply chains. As a result, OEMs must balance technological transition with supply chain flexibility and control over critical components. It may also influence decisions regarding outsourcing, whether production of critical components should remain in-house or be sourced from external suppliers.

In sum, the study indicates that the heavy truck industry is undergoing a gradual but strategically significant sustainability transition. For Volvo Group, long-term competitiveness will depend not only on technological development, but also on the ability to integrate sustainability into business models while maintaining flexibility because of uncertain future conditions.

7 Recommendations and Future Research

7.1 Recommendations

- **Develop Volvo On Demand into a more complete electrification service.** Volvo Group should strengthen the business model by adding route optimisation, charging planning and utilisation support, so that customers receive operational support rather than only access to electric trucks. This could reduce customer uncertainty and support lower Scope 3 emissions.

- **Advance predictive maintenance toward component-specific failure prediction.** Volvo Group should use its connected vehicle data more actively to predict failures in components that affect fuel consumption and emissions. Partnerships with specialised analytics providers could accelerate this development.

- **Prioritise energy reduction in paint shop operations.** Volvo Group should evaluate whether a wet-on-wet painting process can be implemented, since this can reduce drying stages, oven cycles and total energy consumption in production.

- **Reduce hazardous waste through improved painting processes.** Since paint shop operations involve solvents, chemicals and coating materials, Volvo Group should prioritise process changes that reduce hazardous waste and substances of concern, including wet-on-wet painting where feasible.

- **Increase modularity within the Group to improve strategic agility.** Volvo Group should develop more modular platforms, components and production systems to adapt faster under regulatory and geopolitical uncertainty. This would also improve the ability to insource critical technologies and reduce dependence on vulnerable external supply chains.

7.2 Future Research

Future research could include a more detailed analysis of Scope 3 emissions, since these represent the largest share of lifecycle emissions in the heavy truck industry. In relation to this, companies' lifecycle assessments could be analysed to gain a better understanding of the different perspectives and methods used to assess environmental impacts. This would also make it possible to evaluate environmental impacts across the entire vehicle lifecycle in greater detail.

The study could also be expanded by benchmarking additional companies, which would provide a broader understanding sustainability performance within the heavy truck industry.

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A Appendix 1

A.1 Interview Guide

This interview is conducted as part of a bachelor's thesis at Chalmers University of Technology. The project has been assigned by Volvo Group, but the study itself aims to objectively compare several heavy truck manufacturers, including Volvo. The thesis is carried out on behalf of Chalmers and will be publicly published.

Introductory Questions

1. Please introduce yourself, your role, and briefly describe the company you work for.
2. What types of vehicles do you produce?

The goal of these interview questions is to obtain information to answer the research question:

Which sustainability goals are integrated into product development and business models?

1. How are sustainability targets translated into technical requirements?
2. How do you integrate these sustainability goals into product development and business models?
3. Do you use Life Cycle Assessment (LCA), and if so, which stages of the life cycle do you focus on?
4. What internal mechanisms ensure that sustainability goals are not just symbolic but operational?
5. Has your business model changed because of sustainability ambitions, for example through services, circular models, or new revenue streams? Please give a concrete example.

Which sustainability goals are the most critical for achieving significant impact in the heavy truck industry?

1. What makes certain goals more impactful than others?
2. Are there goals that receive significant external attention but have limited real impact? If so, why are those goals kept?

Which emission technologies are currently implemented in your vehicles and manufacturing facilities?

1. Regarding vehicles, do you work with measures such as more efficient engines, improved powertrains, or reduced aerodynamic drag?
2. Regarding manufacturing facilities, do you work with better processes, reduced energy use and waste, or reduced water consumption?

3. How do you balance investments between vehicle decarbonization and factory decarbonization?
4. How do you prioritize between these areas?

Which emission technologies are most critical for achieving a significant reduction in environmental impact?

1. Where have you seen the largest efficiency gains?
2. Where do you see remaining inefficiencies, and how are you working towards solving them?
3. How do you view the development of zero-emission vehicles (ZEVs) going forward in the heavy truck sector?

How are circular material flows implemented in production and in the design process?

1. Regarding tires, do you consider any strategies to minimise the environmental impact from tire wear?
2. How do cost and performance trade-offs influence circular decisions?

To what extent are responsible sourcing practices applied across the supply chain?

1. Where are the most significant environmental risks in your supply chain?
2. How are you working towards minimizing those risks?
3. What have you done to ensure that the energy you use comes from renewable sources?

How might upcoming regulations impact sustainability strategies, operational practices, and performance outcomes in the heavy truck industry?

1. Which emerging sustainability metrics could shape companies' future practices, and in what way?
2. How might lifecycle-based metrics change product design?

How do partnerships influence your sustainability strategy and development across the value chain?

1. What types of partnerships are most critical?
2. What capabilities cannot be developed internally?
3. Do sustainability pressures encourage consolidation or shared platforms?

B Appendix 2

B.1 Scoring System

Product & Supply Chain Scoring	Measurable Variables	1	2	3	4	5
Scope 3 Emissions (Use Phase)	tons of CO_2e per vehicle	>1129	894 - 1129	654 - 893	504 - 653	0 - 503
Total Energy Consumption	Total manufacturing energy use per vehicle (MWh/vehicle)	>14	11 - 14	8 - 11	5 - 8	0 - 5
Particulate Matter in Tire Wear	amount of information available	No mention	Very Limited	Limited	Detailed	Extensive
Substances of Concern	amount of information available	No mention	Very Limited	Limited	Detailed	Extensive

Table B.1: Product & Supply Chain Scoring matrix

Operations Scoring	Measurable Variables	1	2	3	4	5
Non-Recycled Non-Hazardous Waste	% of total non-recycled waste (non-hazardous)	80 - 100 %	60 - 80 %	40 - 60 %	20- 40 %	0 - 20 %
Non-Recycled Hazardous Waste	% of total non-recycled waste (hazardous)	80 - 100 %	60 - 80 %	40 - 60 %	20- 40 %	0 - 20 %
Scope 1 Emissions	tons of CO_2e per vehicle	>1.10	0.88 - 1.10	0.6 - 0.87	0.43 - 0.59	0.00 - 0.42
Scope 2 emissions	tons of CO_2e per vehicle	>1.42	1.16 - 1.42	0.79 - 1.15	0.60 - 0.78	0.00 - 0.59
Renewable Energy use	% of total energy use	0 - 20 %	20 - 40 %	40 - 60 %	60 - 80 %	80 - 100 %
Fresh Water Consumption	m^3 per vehicle	>20	7.29 - 20.00	6.86 - 7.28	5.01 - 6.85	0.00 - 5.00

Table B.2: Operations scoring matrix

C Appendix 3

C.1 Company Calculation Tables

C.1.1 Volvo Group

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{155{,}000{,}000 \text{ tons of } CO_2e}{202{,}911 \text{ vehicles}} = 763.88 \text{ tons/vehicle}$	[38]	47, 153
Total Energy Consumption	$\frac{2224 \text{ GWh}}{202{,}911 \text{ vehicles}} \cdot 1000 = 10.96 \text{ MWh/vehicle}$	[38]	47, 157
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Very Limited	[38]	165, 185

Table C.1: Volvo Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	13%	[38]	162
Non-Recycled Hazardous Waste	59%	[38]	162
Scope 1 emissions	$\frac{203{,}000 \text{ tons of } CO_2e)}{202{,}911 \text{ vehicles}} = 1.000 \text{ tons/vehicle}$	[38]	47, 157
Scope 2 emissions	$\frac{157{,}000 \text{ tons of } CO_2e}{202{,}911 \text{ vehicles}} = 0.774 \text{ tons/vehicle}$	[38]	47, 157
Renewable Energy Use	56%	[38]	157
Fresh Water Consumption	$\frac{5{,}355{,}000 \text{ m}^3}{219{,}377 \text{ vehicles}} = 24.41 \text{ m}^3\text{/vehicle}$	[61]	N/A

Table C.2: Volvo Operations calculation table

C.1.2 Daimler

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{305{,}957{,}000 \text{ tons of } CO_2e}{422{,}510 \text{ vehicles}} = 724.14 \text{ tons/vehicle}$	[40]	2, 89
Total Energy Consumption	$\frac{3{,}295{,}790 \text{ MWh}}{422{,}510 \text{ vehicles}} = 7.8 \text{ MWh/vehicle}$	[40]	2, 95
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Extensive		

Table C.3: Daimler Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	$\frac{4{,}000 \text{ tons directed to disposal}}{311{,}000 \text{ tons total non-hazardous}} \cdot 100 = 1.286\%$	[62]	6
Non-Recycled Hazardous Waste	$\frac{56{,}000 \text{ tons directed to disposal}}{105{,}000 \text{ tons total hazardous}} \cdot 100 = 53.33\%$	[62]	6
Scope 1 emissions	$\frac{383{,}000 \text{ tons of } CO_2e}{422{,}510 \text{ vehicles}} = 0.906 \text{ tons/vehicle}$	[40]	2, 89
Scope 2 emissions	$\frac{487{,}000 \text{ tons of } CO_2e}{422{,}510 \text{ vehicles}} = 1.15 \text{ tons/vehicle}$	[40]	2, 89
Renewable Energy Use	35%	[40]	93
Fresh Water Consumption	$9.8 \text{ m}^3\text{/vehicle}$	[62]	5

Table C.4: Daimler Operations calculation table

C.1.3 PACCAR

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{122{,}676{,}000 \text{ tons of } CO_2e}{204{,}200 \text{ vehicles}} = 601 \text{ tons/vehicle}$	[41] & [63]	9 & 4
Total Energy Consumption	$\frac{953{,}385 \text{ MWh}}{204{,}200 \text{ vehicles}} = 4.67 \text{ MWh/vehicle}$	[41] & [63]	1 & 4
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Limited	[64]	5-7

Table C.5: PACCAR Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	N/A	N/A	N/A
Non-Recycled Hazardous Waste	N/A	N/A	N/A
Scope 1 emissions	$\frac{102{,}430 \text{ tons of } CO_2e}{204{,}200 \text{ vehicles}} = 0.50 \text{ tons/vehicle}$	[65] & [63]	103 & 4
Scope 2 emissions	$\frac{142{,}304 \text{ tons of } CO_2e}{204{,}200 \text{ vehicles}} = 0.70 \text{ tons/vehicle}$	[65] & [63]	103 & 4
Renewable Energy Use	12%	[41]	1
Fresh Water Consumption	N/A	N/A	N/A

Table C.6: PACCAR Operations calculation table

C.1.4 Isuzu

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{97{,}945{,}388 \text{ tons of } CO_2e}{299{,}000 \text{ vehicles}} = 327.6 \text{ tons/vehicle}$	[43] & [66]	87-88 & 3
Total Energy Consumption	$\frac{3{,}960{,}848 \text{ GJ}}{299{,}000 \text{ vehicles}} = 13.25 \text{ GJ/vehicle} = \frac{13.25}{3.6} \text{ MWh/vehicle} = 3.68 \text{ MWh/vehicle}$	[43] & [66]	86 & 3
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Detailed: Chemical management explicitly required in supplier guidelines	[67]	17

Table C.7: Isuzu Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	3% (estimated from high recycling rates and near-zero landfill)	[43]	86
Non-Recycled Hazardous Waste	N/A	N/A	N/A
Scope 1 emissions	$\frac{172{,}302 \text{ tons of } CO_2e}{299{,}000 \text{ vehicles}} = 0.576\text{tons/vehicle}$	[43] & [66]	87 & 3
Scope 2 emissions	$\frac{260{,}785 \text{ tons of } CO_2e}{299{,}000 \text{ vehicles}} = 0.87 \text{ tons/vehicle}$	[43] & [66]	87 & 3
Renewable Energy Use	26% (reported as 'approximately 26% decarbonized electricity')	[43]	12
Fresh Water Consumption	$\frac{2{,}004{,}000 \text{ m}^3}{299{,}000 \text{ vehicles}} = 6.70 \text{ m}^3\text{/vehicle}$	[43] & [66]	86 & 3

Table C.8: Isuzu Operations calculation table

C.1.5 MAN

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{114{,}300{,}000 \text{ tons of } CO_2e}{116{,}033 \text{ vehicles}} = 986.065 \text{ tons/vehicle}$	[46]	3, 15
Total Energy Consumption	7.52 MWh/vehicle	[46]	22
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Very Limited		

Table C.9: MAN Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	$\frac{486 \text{ tons directed to disposal}}{486 + 22{,}369 \text{ tons total non-hazardous}} \cdot 100 = 2.13\%$	[46]	29
Non-Recycled Hazardous Waste	$\frac{3{,}461 \text{ tons directed to disposal}}{3{,}461 + 13{,}884 \text{ tons total hazardous}} \cdot 100 = 19.95\%$	[46]	29
Scope 1 emissions	$\frac{121{,}000 \text{ tons } CO_2e}{116{,}033 \text{ vehicles}} = 1.04 \text{ tons/vehicle}$	[46]	3, 69
Scope 2 emissions	$\frac{46{,}000 \text{ tons } CO_2e}{116{,}033 \text{ vehicles}} = 0.4 \text{ tons/vehicle}$	[46]	3, 69
Renewable Energy Use	$\frac{16{,}311 + 29{,}252 + 239{,}531 \text{ MWh}}{679{,}986 \text{ MWh}} \cdot 100 = 42\%$	[46]	21
Fresh Water Consumption	$\frac{3{,}782{,}772 \text{ m}^3}{116{,}033 \text{ vechicles}} = 32.6 \text{ m}^3\text{/vehicle}$	[46]	30

Table C.10: MAN Operations calculation table

C.1.6 Scania

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{121{,}933{,}000 \text{ tons of } CO_2e}{91{,}220 \text{ vehicles}} = 1{,}336.69 \text{ tons/vehicle}$	[68]	44
Total Energy Consumption	11.0 MWh/vehicle	[68]	48
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Limited	[68]	20, 63, 96

Table C.11: Scania Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	$\frac{37{,}030 \text{ tons directed to disposal}}{127{,}282 \text{ tons total non-hazardous}} \cdot 100 = 29.1\%$	[68]	61
Non-Recycled Hazardous Waste	$\frac{18{,}628 \text{ tons directed to disposal}}{31{,}849 \text{ tons total hazardous}} \cdot 100 = 58.5\%$	[68]	61
Scope 1 emissions	$\frac{66{,}900 \text{ tons of } CO_2e}{91{,}220 \text{ vehicles}} = 0.73 \text{ tons/vehicle}$	[68]	44
Scope 2 emissions	$\frac{58{,}100 \text{ tons of } CO_2e}{91{,}220 \text{ vehicles}} = 0.64 \text{ tons/vehicle}$	[68]	44
Renewable Energy Use	60.8%	[68]	48
Fresh Water Consumption	5 m^3/vehicle	[47]	41

Table C.12: Scania Operations calculation table

C.1.7 International

Metric	Calculations / Values	Source Document	Page
Scope 3 Emissions Use Phase	$\frac{80{,}755{,}000 \text{ tons of } CO_2e}{120{,}528 \text{ vehicles}} = 0.670 \text{ tons/vehicle}$	[69]	1, 2
Total Energy Consumption	$\frac{1{,}500{,}946 GJ}{120{,}528 \text{ vehicles}} = 12.45 \text{ GJ/vehicle} = \frac{12.45}{3.6} \text{ MWh/vehicle} = 3.46 \text{ MWh/vehicle}$	[69]	1, 2
Particulate Matter in Tire Wear	No mention	N/A	N/A
Substances of Concern	Limited	[70]	Entire document

Table C.13: International Product & Supply Chain calculation table

Metric	Calculations / Values	Source Document	Page
Non-Recycled Non-Hazardous Waste	$\frac{33{,}848{,}935 \text{ pounds}}{81{,}416{,}363 \text{ pounds}} \cdot 100 = 41.58\%$	[69]	1
Non-Recycled Hazardous Waste	$\frac{55{,}991 + 159{,}321 \text{ pounds}}{7{,}648{,}287 \text{ pounds}} \cdot 100 = 2.75\%$	[69]	1
Scope 1 emissions	$\frac{40{,}000 \text{ tons of } CO_2e}{120{,}528 \text{ vehicles}} = 0.332 \text{ tons/vehicle}$	[69]	1, 2
Scope 2 emissions	$\frac{95{,}000 \text{ tons of } CO_2e}{120{,}528 \text{ vehicles}} = 0.788 \text{ tons/vehicle}$	[69]	1, 2
Renewable Energy Use	42%	[71]	315
Fresh Water Consumption	$\frac{602{,}000 \text{ m}^3}{120{,}528 \text{ vehicles}} = 4.99 \text{ m}^3\text{/vehicle}$	[69]	1

Table C.14: International Operations calculation table

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