Master's degree thesis

LOG950 Logistics

Challenges of calculating carbon footprints for manufacturers outsourcing their transportation: A case study of Glamox

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Preface and acknowledgements

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Silje Raum

Abstract

The growing awareness and concern for global warming and climate changes is initiating corporate efforts towards measuring emissions throughout their supply chain. Carbon footprint calculators have emerged as a popular tool for measuring emissions, relying on different practises for methodologies and standards. This paper explores the challenges encountered by a manufacturer, Glamox AS, when calculating the carbon footprint of their outsourced freight transportation emissions.

This case study of Glamox AS applies an exploratory sequential mixed method and a single company case study design with embedded sub-units of three participating transportation companies. The conducted research design consists of both quantitative and qualitative approaches with document analysis and follow-up questionnaire as data collection techniques. The literature review presents relevant topics to create a baseline for understanding the processes and driving mechanisms behind calculating the carbon footprint of freight transportation, starting with the concept of carbon footprint, policy frameworks, freight emissions, calculation methods, databases, and carbon footprint calculators.

The quantitative analysis contains a case study of three versions of widely known online carbon footprint calculators, EcoTransIT standard and extended version and NTMCalc basic version, compared with collected data from a transportation company, and the qualitative analysis encompasses results from the follow-up questions. The key findings in this study uncover differences in practises and methodologies used in measuring carbon footprint for freight transportation, with a combination of in-house solutions and outsourced calculations. The motivation for measuring corporate calculations is unison, with individual goals of reducing internal corporate emissions. In addition, the thesis explores the creation of a self-made carbon footprint calculator, attempting to replicate results from commercially available carbon footprint calculators. The results revealed undisclosed information of important influential factors, complex equations, and variability in methodologies affecting the execution.

Key words: *Carbon footprint calculation tools, GHG emissions, transport mode, GHG Protocol Scope 3, category 4, upstream transportation and distribution.*

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List of abbreviations

CO_2 – Carbon dioxide

CEN – European Committee for Standardization

CO_2eq – Carbon dioxide equivalent

ECMT – European Conference of Ministers of Transport

EEA – The European Economic Area

EF – Emissions factor

ETW – EcoTransIT World

EU ETS – European Union Emissions Trading System

GHG – Greenhouse gases

GHG Protocol – Greenhouse Gas Protocol

HC – Hydrocarbon

ICAO – The International Civil Aviation Organization

IMO – The International Maritime Organization

ISO – International Organization for Standardization

NMHC – Non-methane hydrocarbons

OECD – Organization for Economic Co-Operation and Development

PM – Particulate matter

TTW – Tank-To-Wheel

UIC – International Union of Railways

UN – United Nations

UNFCCC - United Nations Framework Convention on Climate Change

WDED – World Commission on Environment and Development

WTT – Well-To-Tank

WTW – Well-To-Wheel

1.0 Introduction

Since 1990, there has been a decrease in greenhouse gases across all economic sectors in the European Union – except for in the transportation sector. Instead, the greenhouse gas emissions from this sector have continued to grow by more than 15 percent between 1990 and 2021 in the EU, predominantly attributed to the increased volumes of inland freight and passenger transport, accounting for nearly a quarter of total greenhouse gas emissions in the EU. Although transport emissions experienced a 13,5% decrease from 2019 to 2020 because of reduced activities during the COVID-19 pandemic, there was a rebound effect of 8.6% in 2021, followed by further growth of 2.7% in 2022. The transport sector continue to be heavily reliant on fossil fuels despite the increasing shift towards electric vehicles and vessels, and member states of the EU anticipate a sustained rise in transport emissions in the upcoming years (Statista 2023; EEA 2023a).

In 2014, IPCC (IPCC 2014) stated that "*Without aggressive and sustained mitigation policies being implemented, transport emissions could increase at a faster rate than emissions from the other energy end-use sectors and reach around 12 Gt CO2eq/yr by 2050*". As per McKinnon (A. McKinnon 2016), this would imply that the transport sector alone would account for 60% of total emissions in a 2°C restricted temperature scenario. Predictions of further growth in emissions from the transport sector have issued a rising concern from governments, shareholders, NGOs, and customers on a global level and a demand for mitigating of climate change (George et al. 2016). This collective awareness is shared by international organisations, e.g. the World Energy Council and United Nations Framework Convention, and through the expanding corporate commitment to Science Based Targets for emissions reduction (Science Based Targets 2023).

In recent decades, the increasing number of environmental policies and regulations issued on political and organisational levels has emerged as a response to the need for improved efficiency and emissions mitigation. For instance, European countries are expected by the EU to decrease their yearly greenhouse gas emissions by 60-80% by 2050 (UNFCCC 2007). Furthermore, numerous companies are proactively moving toward a greener supply chain, following corporates standard in the assessment and reporting of emissions. One of these is the Greenhouse Gas Protocol, where emissions are categorised by direct (scope 1) and indirect (scope 2 and 3) GHG emissions based on resource ownership (GHG Protocol 2004). In addition, this has unlocked a market for several commercially available carbon footprint calculators, becoming an instrumental tool for companies looking for assistance in their calculations of corporate emissions (ETW 2022).

There is particularly a great potential in the freight transportation sector to uncover and reduce corporate emissions using carbon footprint calculators. However, there is a growing need for a transparent and globally recognised CO_2 calculation standard to accommodate the extensive market of clients, including freight forwarders, transport operators, shippers, and other logistic providers. The existing landscape consists of state-supported and self-developed standards by private organisations offering different practises containing regional approaches and various standards for different modes of transport. Nevertheless, the absence of a unified global standard presents challenges in terms of compatibility and accuracy, especially for standards across various modes of transportation (Kellner and Schneiderbauer 2019).

The inconsistencies and different practises in carbon footprint calculations can potentially affect the transparency and accuracy in a supply chain. In example, freight companies provide services for other companies and have access and direct control of the emissions data from transportation activities. In contrast, companies and manufacturers purchasing the transportation services collects the emissions data from potentially several outsourced transportation companies, which they use to assess their total corporate carbon footprint. This enables possible uncertainties and emphasis the challenges a manufacturer such as the case company of this thesis, Glamox AS, may encounter when calculating carbon footprint for outsourced transport services.

1.1 Research objective

This thesis seeks to investigate the challenges associated with measuring carbon footprints and evaluate the accuracy and transparency of carbon footprint calculators. It aims to explore the motivations behind why companies measure and report their carbon emissions, considering factors of increased environmental concern, regulatory pressures, and customer expectations. The research places special emphasis on assessing the methodologies employed in calculating and reporting carbon emissions by the transportation companies, particularly in the context of road transport, evaluating their consistency and replicability against commercially available calculators. Furthermore, the study will investigate the accuracy and functionality of carbon footprint calculators as tools for measuring a manufacturer's carbon footprint from transportation. Comprehending the fundamentals behind carbon footprints, the driving policy frameworks, how the transportation emissions effects the environment, emission databases and other key concepts behind the calculation of emissions, and the background of the calculation tools EcoTransIT and NTMCalc are all essential to accomplish these objectives.

1.2 Research Questions

Research questions are a central part of a study, designed to provide a clear direction for the research process and analysis of specific topics or issues. The following research questions have been formulated in alignment with the research objectives and designed to reflect the selected methodical structure for this thesis, with a quantitative focus on "*how*" and a qualitative exploration of "*why*".

RQ1 Why do companies engage in carbon emissions measurement and reporting?

RQ2 How do transportation companies calculate and report their carbon emissions for road transport?

RQ3 How consistent and replicable are the emissions calculations by transport companies for road transport compared to commercially available calculators?

RQ4 Does a carbon footprint calculator function as an accurate tool for measuring a manufacturers carbon footprint from transportation? Why/why not?

1.3 Structure of the thesis

The structure of this thesis encompasses eight main chapters, following the recommended guidelines by Molde University College. Chapter one contains the introduction of this thesis, followed by the research objectives, research questions, structure, and limitations. Chapter two introduces the literature review of carbon footprint, political legislations, frameworks, and emissions trading for transportation emissions, emissions caused by four freight transportation modes, calculation methods to measure emissions from transportation, key emissions quantification concepts and factors WTW, WWT, and TTW, databases, standards, guidelines, and frameworks for measuring emissions, and lastly, carbon footprint calculators. Chapter three describes the case company and background for the case study. Chapter four includes the methodology used in this research. Chapter five presents the results and analysis and findings of the quantitative and qualitative data collection. Chapter six is the conclusion and answer to the research questions. Chapter seven include future research, and finally, chapter eight display the references.

1.4 Limitations

The literature review of this thesis will explore the environmental impacts of the transportation modes from road, rail, sea, and air freight. However, the scope of the cases, data collection and analysis are confined to road transportation and will exclude other transportation modes. The amount of data needed, time constraint, and complexity of multiple transportation modes makes it difficult to achieve comparable results across cases. The analysis will specifically focus on freight transportation within Europe and exclude passenger transportation. In addition, the data collection is reliant on available data and information from selected companies and variations in industry practices, potentially restricting the generalisability of findings, and bounded by the accessibility of specific tools and databases.

2.0 Literature review

2.1 Carbon footprint

The concept of ‘carbon footprint’ are widely used in public discussions regarding responsibility and efforts to combat global climate change. In recent years, there has been a significant increase in the appearance of this concept, with widespread usage observed across nations, the media, and the business community. Despite its frequent appearance, a precise definition, standardised measures, and units for carbon footprint are lacking. The term originated from ‘Ecological footprinting’ (Wackernagel 1996), where it initially referred to a specific amount of gaseous emissions associated with consumption activities or human production, all linked to climate change. However, this definition was limited due to the lack of consensus on measurement and quantification methods, with definitions ranging from direct CO_2 emissions to full life-cycle greenhouse gas emissions and unclear units of measurements (Wiedmann and Minx 2008).

The early establishing of the concept gave rise to questions of what is included in this term, regarding if it should be restricted to only carbon-based gases or include non-carbon substances like Dinitrogen Oxide (N_2O). Moreover, if it should be restricted to substances with greenhouse warming potential, like carbon monoxide (CO) which can be converted into CO_2 in the atmosphere, or only include CO_2 and other greenhouse gases such as methane. And lastly, if the measurements should include all emission sources, including non-fossil fuel sources such as CO_2 emissions from soils (Wiedmann and Minx 2008). While these questions were discussed and assessed over the years, a clear definition of carbon footprint remained inconclusive, resulting in various definitions proposed by different researchers. Finally, Wiedmann and Minx proposed a comprehensive definition in their article "A Definition of Carbon Footprint.":

> “*The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product*.” (Wiedmann and Minx 2008)

This definition considers all direct and indirect emissions from a wide range of sources, including those of populations, individuals, processes, organisations, companies, industry sectors and governments, as well as products including goods and services. The definition focuses exclusively on CO_2 emissions, acknowledging the presence of other substances with greenhouse warming potential. To address a broader range of gases, a comprehensive indicator termed "Climate Footprint" would be more suitable. Nevertheless, the definition rejects the notion of representing carbon footprint as an area-based indicator, emphasizing that the total amount of CO_2 emissions is measured in mass units like kilograms or tons, rather than converting it into an area unit like hectares. Any conversion to an area-based measure would require multiple assumptions, leading to increased uncertainties and errors in footprint estimates. Therefore, a representation in terms of CO_2 is preferred over an area-based measure (Wiedmann and Minx 2008).

Wiedmann and Minx's definition highlights that the carbon footprint is a useful tool for individuals and companies to measure their carbon emissions during a project or timeframe. There are generally two primary motivations for determining a carbon footprint: accurate reporting of the footprint to third parties and managing the footprint and reduce the emissions over time (Carbon Trust 2007). In the last decades, the interest of calculating the carbon footprint has increased among organisations and companies for various reasons such as marketing, achieving carbon neutrality by offsetting emissions, or meeting demands from customers and stakeholders. The findings from a survey released in 2011 among 9,000 people in eight different countries found increased awareness of carbon footprint from producers and costumers to buy from environmentally friendly companies and that green certifications influence buying behaviour positively (Swallow and Furniss

2011). In addition, other market strategies include offering consumers carbon labelled products, and investors incorporate carbon footprint in their portfolios as an indicator of investment risks (Hertwich and Peters 2008).

Understanding and monitoring the carbon footprint serves as an effective tool for continuing environmental and energy management for an organisation. However, the intricate nature of supply chains, encompassing various processes involved in the production of goods and services, along with global trade connections between nations, poses a challenge to accurately assign GHG emissions to their specific causer (Hertwich and Peters 2008). In addition, new concepts designed to minimize costs and inventory at warehouses, such as just-in-time, has increased the emissions from the transport sector. It is therefore necessary to integrate environmental thinking to the traditional focus of supply chain management goals of lead time optimisation, cost reduction, value creation and demand for effectively addressing and modelling the carbon footprint of transportation and the supply chain. (Sundarakani and de Souza et al. 2010). Moreover, to ensure accurate calculations, a comprehensive approach is needed, considering all emissions of which the organisation is responsible (Carbon Trust 2007).

2.2 Political legislations, frameworks, and emissions trading for transportation emissions

Environmental policy refers to the set of principles, laws, regulations, and initiatives that aim to promote the protection, conservation, and sustainable use of the natural resources (European Parliament 2022). It is a supranational issue that requires international cooperation and consensus-building to address. However, each continent and country have its own set of laws and regulations, making it difficult to implement changes on a global scale. Despite these challenges, there have been efforts to develop international agreements and frameworks to guide regional and global action on environmental issues.

The first global initiative came with the report “Our Common Future”, also known as the “Brundtland Report”, published in 1987 by the World Commission on Environment and Development (WCED), an institution of the United Nations (UN). The report was endorsed by 99 global member countries of The UN and proposed a sustainable development approach that recognizes the interdependence of environmental, economic, and social sustainability, with a purpose to provide policy recommendations and frameworks for achieving sustainable development (United Nations 1987). Following this, The UN established The United Nations Framework Convention on Climate Change (UNFCCC) in 1992, as the main international agreement on fighting climate change. With its currently 197 member countries the purpose is to prevent dangerous interferences with the global climate system (United Nations 1992).

In 1997, The UNFCCC adopted the international treaty, The Kyoto Protocol, with the aim to combat global warming by setting legally binding emission reduction targets for industrialised countries. The Protocol targets the reduction of six greenhouse gases, including carbon dioxide, methane, and nitrous oxide, expressed as a percentage of 1990 emission levels (United Nations 1997). The primary option for countries following the Protocol was to meet their emissions targets through national measures, however, additional three flexible marked mechanisms based on the trade of emissions permits were offered: International Emissions Trading, Clean Development Mechanism (CDM), and Joint Implementation (JI) (United Nations c2023c). Due to a complex ratification process the Protocol was first officially enforced in 2005, and although it has been ratified by 192 UNFCCC Parties there are still many major emitters member countries which never ratified or withdrew their participation, for instance the USA and Canada, and therefore the Protocol only covers about 12% of global emissions. Since initiated, there have been two commitment periods with reduction goals in percentage of 1990 emissions and with a variation of participating countries: 1st period from 2008-2012 with 5% reduction, and 2nd period (The Doha Amendment) from 2013-2020 with 18% reduction (European Commission c2023a).

In 2015 at the UN Climate Change Conference (COP21) in Paris, 196 Parties in the UNFCCC adopted The Paris Agreement, which is the first-ever universal, legally binding international treaty on climate agreement. In contrast to the Kyoto Protocol, this agreement quickly entered into force in 2016, with the main objective to limit the average global temperature of increasing above 1.5°C pre-industrial levels by the end of this century (United Nations 2015). Because of the urgency, the GHG emissions needs to peak latest by 2025 before declining 45% by 2030 in order to reach the long-term goal of net-zero emissions by 2050 (United Nations c2023b). The implementation of the agreement requires social and economic transformation and provides a framework to avoid climate changes through capacity building, financial and technical support for all countries. The participating countries each submits their Nationally Determined Contributions (NDCs) and Long-Term Low GHG Emission Development Strategies (LT-LEDS), with further establishment of an Enhanced Transparency Framework (ETF) starting in 2024 to encourage the countries to report their progress to the Global Stocktake for assessing the collective progress. The current achievements from the contributions has initiated carbon neutrality targets among countries, regions, and companies, and created new markets and low-carbon solutions, especially in the transport and power sectors (United Nations c2023a).

2.3 Emission caused by freight transportation

As previously reviewed, implementation of environmental policies displays multiple approaches and challenges faced by institutions in their efforts to restrict and reduce greenhouse gas (GHG) emissions. The complexity arises due to the global scale of the issue and the involvement of numerous emission sources. Among these sources, transportation is a significant contributor to pollution, and different modes of freight transportation hold unique characteristics and specialties that requires tailored strategies to achieve emission reduction. For instance, while the Kyoto Protocol addresses actions towards emissions from various sectors and the Paris Agreement does not directly include sea and air freight (UNFCCC 2016), UNFCCC has assigned the responsibility for regulating sea and air transport emissions to The International Maritime Organization (IMO) and The International Civil Aviation Organization (ICAO), as bodies of the UN (ECMT 2007). The EU adopt and impose binding standards and regulations on its member states, however, the implementation of these regulations into national law varies among member states, further complicating the situation in the transportation sector. The following chapters explore the details of the four most common freight modes in relation to emissions handling.

2.3.1 Road transport emissions

Road transport represents a substantial contributor to the EU's GHG emissions, accounting for 77% of the total emissions from the EU-27 transport sector in 2020. Although efforts to align with the goals of the European Green Deal has been implemented, the sector is not improving fast enough as it followed a period of steady growth in both road transport and consequently GHG emissions from 2013 to 2019. The COVID-19 pandemic led to a significant decrease in emissions in 2020, however, preliminary estimates for 2021 indicate a rebound with a 7.7% increase in transport emissions (EEA 2023b).

The main GHG emissions of the road transport sector is CO_2 emissions, accounting for approximately 99% of total emissions from this sector. Cars and heavy-duty vehicles (HDV) (include coaches, trucks, and buses) are responsible for 88% of the total road emissions, and passenger cars and heavy goods vehicles increased their CO_2 emissions by 5,8% and 5,5% between 2000 and 2019. The main driving factor behind this growth is the increase in demand, which follows the global economy, but also the growth in the modal share of car transport and an increase of carbon intensity of the fossil fuels consumed by passenger cars are contributing. Similarly, during the same period demand for inland freight transport increased with 25% and the emissions from the heavy goods vehicles (HGV) increased with 5,5%. On the contrary, higher energy efficiency of passenger cars and higher share of biomass fuels are two main factors of energy efficiency improvements which counteracts the effects of transport activity and lower CO_2 emissions. In addition to CO_2 emissions, CH_4 and N_2O, weighted by their global warming potential, made up 1% of the GHG emissions from passenger cars in 2019. For HGV, these emissions decreased between 2000 and 2004 but has since 2009 increased again due to higher emission intensity of the fuels used by HGV (EEA 2022).

There have been notable improvements in the CO_2 efficiency of the overall vehicle stock, encompassing both heavy goods vehicles and cars. This is explained in part by advancements in operational and fuel efficiency (EEA 2022). However, despite recent progress toward electric vehicles, most vehicles in the EU still rely on petrol or diesel, which emit air pollutants and other particulate matter (PM). In addition, noise pollution poses a significant but often overlooked health concern for individuals residing or working near major roadways. Furthermore, the expanding reliance on road transport and the growth of road networks have adverse effects on biodiversity by fragmenting and reducing natural habitats, thus impeding the movement and migration of wildlife (EEA 2023b).

The EU is actively shaping sustainable road transport through key policies, primarily driven by the European Green Deal and the Sustainable and Smart Mobility strategy. The European Green Deal sets ambitious targets to significantly reduce transport-related greenhouse gas emissions, aiming for a 90% reduction and a climate-neutral EU by 2050 (EEA 2023b). To drive this progress, the EU published a set of '*Fit for 55*' package or '*Delivering the European Green Deal*' package in 2021, which especially contain new legislative proposals for the road sector to reduce CO_2 emissions by 55% by 2030 and improve energy efficiency and consumption (EEA 2022). Most of the legislative acts proposed by the EU are based on the "*polluter pays*" approach, which assigns the costs of pollution (including social and costs) to the operator or shipper (Mayer et al. 2012). In road transportation, this principle is primarily achieved through taxes on fuel and toll systems for road usage, which vary between countries. In example, implementation of the Energy Efficiency Directive and the Energy Taxation Directive confirmed that higher taxes contributed to have played a significant role in promoting fuel efficiency in cars, resulting in lower average CO_2 emissions per vehicle-kilometre in the EU compared to the United States, where prevailing fuel taxes are lower (Eberhard and et al. 2000).

Road transport, including private vehicles, accounts for a significant portion of overall emissions, particularly when compared to sectors such as shipping where passenger ships represent only 3% of total CO2 emissions (OECD 2008). Further analysis of road emissions differentiates between the various types of vehicles, private cars, heavy-duty vehicles (HDV) and light-duty vehicles (LDV). HVDs refer to all types of trucks weighing over 3.5 tons, while LDVs are trucks with a weight limit of 3,5 tons. Over the past decades, key legislation aimed at reducing road emissions has included the shift from leaded to un-leaded fuel, sulphur-free fuel, and the implementation of European Union emission standards and regulations for vehicles within the EU (DieselNet 2021). These emission norms impose maximum limits on emissions exhausted from road transport, distinguishing between types of vehicles and petrol and diesel fuel types. It started with the introduction of EURO I standard in 1992 for HDV and Euro 1 in 1993 for passenger cars and LDV (dividing the standards and vehicle types by Roman and Arabic numbers), with regulations of CO_2, CO, HC (hydrocarbon), NMHC, CH_4, NO_X, and PM emissions measured in grams per kilometre (g/km). Since then, further developments of the standard have been implemented and additional emissions and measures have been added. For instance, emission limits for PN (particle number) were introduced in 2011 with Euro 5 for LDVs and in 2013 for HDVs, and EURO III added measures for smoke for HDVs in 1999 (DieselNet 2022).

The current required standard is Euro 6/EURO VI, which was introduced in 2014. In 2022, the European Commission proposed Euro 7/EURO VII as part of the European Green Deal and the zero-pollution objective. The new rules will have a longer lifespan for vehicles and will regulate emissions from tyres and brakes for the first time globally. In addition, the proposal includes new limits and procedures for battery durability, supporting the transition towards electrification (European Commission c2023b).

Despite the projected increase in transport demand and activity, various counteracting factors are expected to contribute to the current policy frameworks anticipation of 35% reduction in CO_2 emissions from road transport by 2050. Energy efficiency will be a key factor in reducing road emissions, together with the increasing effect from electrification. On the contrary, modal shift and biofuels will have limited impact. Achieving future sustainability in road transport goes beyond efficiency gains, electric vehicles, or cleaner fuels. It requires evaluation of the environmental impact related to the life cycle of vehicles, and a comprehensive transformation of the mobility system, including reevaluating mobility needs and exploring alternatives such as public transport, active mobility, and cleaner modes of transportation (EEA 2022).

2.3.2 Sea transport emissions

Maritime transport is considered one of the key cornerstones enabling globalisation (Kumar and Hoffmann 2002). While 90% of world trade is moved by sea, the EU carries 77 % of external trade and 35 % of intra-EU trade, employing 1 million in the whole maritime sector (EMSA and EEA 2021). Over the past 40 years, the volume of maritime transport has grown by 250%, resulting in continued growth in GHG emissions from the shipping industry (IPCC 2022). Although the maritime sector brings significant social and economic benefits to the EU, the sector accounts for 13,5% of all transport-related GHG emissions, in which 13% SO_X and 15% NO_X (EMSA and EEA 2021; Istrate et al. 2022).

Shipping has long been regarded as an environmentally superior option compared to road haulage, earning the reputation of being the "*green mode*" of freight transport. Furthermore, additional policy papers and academic literature largely support the perspective put forth by the International Maritime Organization (IMO) that shipping stands as the "*most energy efficient mode of mass cargo transportation*" (IMO 2017). This consensus is reinforced in EU transport policy papers, which highlight shipping as a more CO_2 efficient mode compared to road haulage (EC 2011). As a result, these assertions have explicitly or implicitly guided the establishment of European policies aimed at shifting cargo from road to sea transport (Aperte and Baird 2013; Ancor Suárez-Alemán 2016; A. Suárez-Alemán, Trujillo, and Medda 2015). However, the environmental issues associated with sea transport are many. “The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes” (IMO

2019). The development of the MARPOL convention was a direct response to several instances of accidental pollution in international shipping, leading to its adoption by the International Maritime Organization (IMO) in 1973. The convention has a number of annexes that are regularly updated to minimize pollution from ships, including restricted concentrations of air polluting matters like CO_2, SO_X, NO_X, HC and PM in fuel used by vessels, which are the most significant emissions by shipping to the atmosphere (Matthias et al. 2010).

The initial political and environmental focus, as seen in the IMO MARPOL convention, targeted emissions to the sea. However, in recent decades, there has been an increased focus on air emissions, which were incorporated into the regulatory regime of shipping with the introduction of Annex VI to the MARPOL convention in 2007. Environmental hazards associated with air emissions are typically categorised as having global, regional, or local impacts. Global warming, a global-scale issue, is given the main attention on the political agenda, primarily addressing direct emissions of GHG and the manufacturing processes associated with vehicles and vehicles. Emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) may cause acidification and harm to buildings and crops and are therefore main areas of concern on a regional (international) scale. In addition, seaborne transport presents various regional issues concerning emissions to the sea which can disrupt the regional marine environment, including waste disposal, oil spills, and the discharge of ballast water. At the local level, the most significant impacts are associated with poor air quality caused by emissions into the atmosphere, with a particular focus on SO_2, NO_X, non-methane volatile organic compounds (NMVOC), hydrocarbons (HC) and particles (Whall et al. 2002). Apart from air emissions, additional local concerns include noise effects, severance, vibration, landscape impairment, visual intrusion, and the effects stemming from local water and soil pollution (Bickel and Droste-Franke 2006).

To gain a comprehensive understanding of emissions caused by sea transport, it is important to consider several aspects. For instance, the operating location of the vessel plays a significant role, whether it is in a port, on open seas, or in special areas such as channels or controlled zones. While seaborne transport primarily occurs far away from residential areas, local impacts can be significant in certain cases where ports or inland waterways are situated within cities or close to the coast. Ports with long river or canal approaches can result in high local air emissions and potential noise pollution (Meersman et al. 2006). Approximately 70% of all air emissions from shipping are estimated to occur within 400 km of land, affecting the air quality of nearby residential areas (Eyring et al. 2010). Furthermore, vessels spend considerable time in ports and coastal areas adjacent to residential zones, and each area has its own restrictions regarding engine and fuel requirements. For instance, the IMO determines maximum levels of PM, NO_X, and SO_X emissions in ECA regions, which stands for Emission Control Area and concerns countries in Europe and Central Asia. While vessels are approaching a port or berthed, auxiliary engines are commonly used to generate onboard electricity for manoeuvring equipment operations and cargo handling. Auxiliary engines run on Marine Diesel Oil, which is more expensive but has lower levels of air pollutant-causing chemicals such as CO_2, NO_X and SO_X compared to the cheaper Heavy Fuel Oil used for main engines on open waters (Matthias et al. 2010; Jayaram et al. 2011).

The quantification of the impact of maritime emissions is a complex task, considering its global, regional, and local effects. The growing awareness of global warming has led to extensive research on carbon emissions, with a particular focus on the transportation sector and the need to include it in climate policies. However, allocating emissions from international shipping and aviation to underwriting nations has been challenging, and these sectors have been exempted from collective global environmental policy initiatives, with regulations falling under the purview of IMO and ICAO. Previous studies, such as (Eyring et al. 2010), (Endresen et al. 2007) and (Corbett et al. 2007), have contributed to the research of marine sector by examining the overall net effect of emissions to air and environmental footprint of shipping, with emphasis on fuel consumption, demand, and other determining factors. (Eyring et al. 2010) reviews the effects of emissions from shipping, revealing counteracting forces resulting in a negative net radiative forcing, while NO_X and SO_X contribute to local air pollution. More recent studies, in a report by the Joint Research Centre (JCR) and published by the European Commission, performs analyses of the GHG emitted by ships in EU ports in 2019, followed by a meta-study of the life cycle assessments (LCA) on maritime systems and alternative fuels. The study found that the combustion of fuel during ship operation is the most important life cycle stage from a climate change perspective, and highlights the importance of promoting alternative clean fuels (Istrate et al. 2022).

Decarbonizing the maritime sector is becoming increasingly urgent despite its relatively lower contribution to global greenhouse gas (GHG) emissions. There are three key reasons driving this urgency. First, as shipping is expected to grow substantially in the coming decades, its GHG emissions are projected to increase by 90-130% between 2008 and 2050 (IMO 2020). Second, decarbonizing shipping poses challenges due to the lack of mature and readily deployable technologies. Third, the long service life of vessels (30 to 40 years) necessitates quick action to avoid prolonged locked-in emissions. These reasons have prompted various global and European initiatives to specifically target GHG emissions from shipping. The IMO has implemented measures to enhance energy efficiency and cap GHG emissions. The introduction of the Energy Efficiency Design Index (EEDI) in 2011 and its mandatory limits for ships built since 2013, along with the requirement for an energy efficiency management plan, mark significant milestones (IMO 2018). While improving energy efficiency is crucial for emission mitigation, it alone is insufficient. Additional actions, such as adopting cleaner fuels, reducing speeds, innovating ship designs, technological advanced engines, implementing emission abatement systems, and enhancing ship hull efficiency, are necessary for achieving a long-term downward emission trend (IMO 2015; Lindstad et al. 2015; Istrate et al. 2022).

2.3.3 Rail transport emissions

Rail transport is a key component in reducing emissions within the transportation sector due to its efficiency in both freight and passenger operations, and subsequently lower GHG emissions per passenger-km (pkm) and tonne-km. In EU-27, the efficiency of passenger and freight rail transport improved by 13% and 11% respectively between 2014 and 2018, primarily driven by rail network electrification and the decreasing carbon intensity of the electricity mix (EEA 2021; FRA 2022). The sector is considered the lowest CO_2 emitter in terms of "tailpipe" emissions and in 2018 rail transport (diesel trains only) accounted for 0,4 % GHG emissions from transport in the EU-27 (EC, 2020b), with additional studies suggesting that total rail emissions account for 1%-3% of the total global transport emissions (IEA 2017).

Furthermore, direct CO_2 emissions from diesel rail operations increased by less than 1% per year over the last two decades until 2019, whereas electric rail, which accounts for around 80% of passenger rail activity and 50% of freight movements, emits no direct CO_2 emission (IEA 2022).

The emissions associated with rail transport extend beyond direct CO_2 emissions, as the production, transport, and transmission of fuels and electricity consumed by trains result in indirect GHG emissions known as "Well-to-Tank" (WTT) emissions. Rail travel demand, in combination with other factors, determines these emissions, which include: the GHG emission intensity of energy consumed by rail, rail traffic management procedures, the number of passengers on the trains, and the specific energy consumption of passenger trains (energy per vehicle-km). Diesel trains emits air pollutants, although both diesel and electric trains impacts water and soil pollution and cause non-exhaust particulate matter (PM) and release of metals and hydrocarbons from powerline abrasion, wheels on tracks, and brakes. Rail traffic noise is an additional large issue with high level of exposure (EEA 2021). Furthermore, the construction, operations, and maintenance of rail infrastructure are the largest contributors of total emissions from this sector, which need to be offset by the reduced emissions from rail transport itself to ensure environmental benefits (Lawrence and Bullock 2022; EEA 2021).

Climate change and extreme weather events pose significant risks to the operations and infrastructure of the rail sector, exposing its vulnerability and impacting its effectiveness, safety, sustainability, equity and reliability of the rail network (FRA 2022). Extreme weather events like heat waves, heavy rainfall, and flooding can lead to infrastructure failures, necessitating proactive measures, infrastructure maintenance, and emergency planning to ensure the resilience of rail transport against the adverse effects of changing climate-related weather events (Palin et al. 2021; Anderton et al. 2023).

The low carbon emissions and energy efficiency compared to other transport modes makes rail an important contributor to realising a decarbonised future by 2050. Transportation could become more carbon efficient through modal shift from more carbon-intensive modes to rail, which has the greatest impact on GHG emissions and accounts for roughly 80% of the potentially possible savings. Additional climate benefits can be achieved by enhancing the technical, operational and extension possibilities of rail networks, particularly in developing countries with growing demand for goods, while also supporting increased mobility and economic growth (Lawrence and Bullock 2022; IPCC 2022). Although diesel locomotives remain prevalent, there is a rising interest in alternative low-carbon propulsion technologies such as electricity, efficient storage, synthetic fuels, biofuels, ammonia, and hydrogen, with electrification of rail systems already being established throughout Europe (IPCC 2022).

The choice of transport mode is determined by multiple factors beyond door-to-door costs, such as: freight value, last-mile connectivity, speed, transit time, distance, minimum consignment size, reliability, flexibility, frequency, infrastructure, information, service quality, accessibility, resilience, environmental impact (ITF 2022; Lawrence and Bullock 2022). Rail transport proves most competitive for bulk cargo and linehaul movements due to its significant cost benefit (Lawrence and Bullock 2022). High-speed rail (HSR) is considered environmentally friendly with its high occupancy rate (EEA 2021), while electric rail systems serve urban areas and intercity networks efficiently (IPCC 2022). However, because railways cannot provide last-mile service and require new infrastructure, they are mostly used intermodally. Railways support green development and provide affordable, eco-friendly transportation that fosters inclusive economic growth, especially in developing countries. However, transitioning from diesel to alternative energy sources like electricity and hydrogen requires accessible, reliable, and environmentally friendly power options. Furthermore, rail can generate increased transport demand, however, developing countries often encounter challenges in adequate power generation, ensuring reliable distribution, and shifting away from fossil fuel-based energy (EEA 2021; Lawrence and Bullock 2022).

The 2020 European Commission's Sustainable and Smart Mobility Strategy highlights the importance of transitioning to sustainable transport modes and fundamentally transforming the mobility system for sustainability, aligning with the European Green Deal and emissions reduction. The strategy aims to establish an 'affordable high-speed rail network' in Europe and targets a 50% increase in rail freight transport by 2030, doubling by 2050, while implementing applicable incentives to facilitate the mode transition and the operation of the multimodal Trans-European Transport Network (TEN-T) by 2050 (EC 2020). About 72% of rail transport occurs on electrified lines, and the European Union Emissions Trading System (EU ETS) is significant in incentivising the electrification of rail infrastructure for the TEN-T ‘core network’ (EEA 2021). However, the 2020 world energy crisis has had a significant impact on railways, which are among the largest consumers of electricity in their respective countries, prompting the establishment of the Energy Saving Taskforce by UIC (International Union of Railways) (Anderton et al. 2023).

2.3.4 Aviation transport emissions

Aviation has become the second largest source of emissions in the transport sector, following road transport, and the increase is the result of emissions reductions in other sectors and traffic growth outpacing fuel efficiency developments (EASA 2022). Domestic and international aviation combined accounts for about 2% of total global CO_2 equivalent emissions. International aviation accounts for approximately 1,3% of total global CO_2 emissions and is estimated to be about 4,9% of total global anthropogenic with non-CO_2 greenhouse effects included (ICAO 2016; Lee et al. 2010). In 2018, flights departing from EU27+EFTA (European regions) contributed to 16% of CO_2 emissions from global aviation, with all departing flight from Europe accounting for 5,2% of the total EU27+EFTA GHG emissions and 18,3% of the transport sectors in 2019.

Air transport is an essential transport mode of the global trading system and is frequently utilized for time-sensitive and perishable items with a high value-to-mass ratio (Howitt et al. 2010). However, the aviation sector has significant environmental impacts and the primary GHG emitted is CO_2 from the combustion of fossil fuel aviation kerosene (Jet-A), which contribute to climate change as the emissions remain in the atmosphere for long periods, accumulating and increasing CO_2 concentrations over time (IPCC 2022; EASA 2022). In addition, the sector is a notable source of air pollutants, which have adverse effects on air quality and human health, particularly in urban areas (EC 2021). NO_X, PM, and ground-level ozone (O_3) are among the most significant air pollutants, and the EU has seen an increase in these emissions from aviation despite overall emission reductions and general improvements. Although aircraft operations are a major source of air pollution in the surrounding area of airports, other factors such as surface access road transport, ground support equipment, and airport on-site energy generation also have an impact on air quality. Furthermore, aircraft engines emit similar pollutants to other sources of fossil fuel combustion, including PM, SO_2, carbon monoxide (CO), volatile organic compounds (VOCs), and unburnt hydrocarbons (HC). Other environmental impacts include high level of noise disturbances, contrail-cirrus (condensation trails from airplanes), and soot (EASA 2022).

Aviation is acknowledged as a “hard-to-decarbonise” sector (Gota et al. 2019) due to its heavy reliance on liquid fossil fuels and the long-term infrastructure investments, leading to slow fleet turnover times and limited flexibility for adopting alternative technologies. The net warming effect of the sector are results from its past and present emissions of both CO_2 and non-CO_2 emissions. This indicates that a remainder of CO_2 emissions today will continue to contribute to warming for many thousands of years (Archer et al. 2009; Canadell et al. 2021), while NO_X, soot, and water vapour will diminish their contribution to warming within a few decades. Therefore, achieving net-zero CO_2 emissions in aviation, as required by 1.5°C scenarios, necessitates substantial transformation in technology, changes of demand or behaviour, or fuel options (IPCC 2022).

Safety considerations remain an overriding constraint in driving technological advancements and improving energy efficiency within the sector, and the current literature suggests limited potential for major energy efficiency improvements in line with projected air transport growth (IPCC 2022). However, operational improvements for navigation have been made, and alternative lower-carbon bio- or synthetic aviation fuels are deemed essential to meet growing demand without increasing CO_2 emissions (Klöwer et al. 2021). Although the development of sustainable aviation fuels (SAFs), including bio-SAFs and non-bio synthetic fuels, have shown promise in reducing the sector's carbon footprint (Chiaramonti 2019; Schmidt et al. 2016), cost barriers and blending limitations need to be addressed for SAFs to be economically competitive. Liquid hydrogen (LH_2) is an additional explored fuel option, primarily for shorter to medium-haul flights, but it requires airplane re-design of thicker wings or larger fuel space (Brewer 1991; McKinsey 2020).

As previously mentioned in the chapter about sea transport emissions there are difficulties in allocating emissions from aviation. International aviation emissions are reported separately as their own category ‘bunker fuels’, with no government accepting liability for them, whereas domestic transportation impacts are included in each country’s overall GHG emissions accounts. As a result, there are limited incentives for countries to mitigate and reduce them since international aviation emissions do not contribute to the emissions of any specific country, and the responsibility for regulating has thus been handed to the UN body, ICAO (Ritchie 2020; Istrate et al. 2022). Market-based offsetting measures have been implemented to address aviation emissions. The EU incorporated aviation into its CO_2 emissions trading scheme (ETS) in 2012, while globally, ICAO established the *Carbon Offsetting and Reduction Scheme for International Aviation* (CORSIA) in 2016 to be commenced in 2020 (IPCC 2022). In addition, exploring modal shift to high-speed rail (HSR) has gained interest as a potential strategy to regional flights, especially in the context of achieving net-zero emissions by 2050 (IEA 2021). While the Paris Agreement does not explicitly cover emissions from international flights, some countries and regions have expressed intentions to include international aviation in their net-zero commitments. However, governance and accounting for international aviation emissions remain complex, and in a recent report from 2022 ICAO continues to explore long-term aspirational goals for emission reductions in the aviation sector.

2.4 Calculation methods to measure emissions from transportation

2.4.1 “Top-down”

There are two main approaches for calculating fuel consumption and emissions from freight transportation activities: “*top-down*” and “*bottom-up*”. The most common for all transport modes is the “*top-down*” approach, also known as the “*fuel-based*” method, and this method calculates emissions based on the consumption of fuel. This is calculated in laboratories, where the burning process and subsequent emissions are dependent on the fuel's chemical consumption. The total estimated emissions from transportation are then calculated as the energy or fuel consumption multiplied by an applicable “*emissions factor*”, as seen in the equation below (Psaraftis 2016):

$$\boldsymbol{Emissions = Energy\ or\ Fuel\ Consumption \cdot Emissions\ Factor}$$

Emissions factors (EFs) are described as the emitted pollutant mass (g) for a travelled distance (km or mile) and are functions of type of emissions, fuel, and engine of the vehicle. Although the most accurate emission estimations are those based on *actual* fuel consumption data, empirically established EFs and other methods of collecting data are used instead. For instance, the emission models for road traffic emissions are based on measurements from dynamometers for a number of single vehicles evaluated under proper driving conditions, as well as model calculations of mileages for these conditions (Colberg, Tona, Catone, et al. 2005). However, there is an uncertainty that these methods and computations of emissions in laboratories will provide the same results or will differ from actual emissions estimations in real life. There are multiple factors affecting emission, depending on the mode of transport combined with a variety of conditions, such as road, speed, payload, load weight, water currency and wind for road, rail, sea, and air transportation. Because of all these aspects, there are an almost infinite number of combinations and settings (Colberg, Tona, Stahel, et al. 2005; Hueglin, Buchmann, and Weber 2006). In addition, this method estimates emissions using fuel sales, which initially makes it the most reliable method of estimating total fuel consumption and emissions. However, fuel sales statistics derived primarily from energy databases released by the Energy Information Administration (EIA), the International Energy Agency (IEA) and the UNFCCC might be highly unreliable or inaccurate (Psaraftis 2016).

2.4.2 “Bottom-up”

The second main approach is the “*bottom-up*” method, also referred to as the “*activity-based*” method. This method is based on “fleet activity” and is using transportation activity modelling or conversion factors that convert the available “activity data” into emissions. It combines data on movements and vehicle characteristics, such as vehicle type, size, engine type, age, fuel, etc, as well as associated fuel consumption statistics and emission factors. For instance, conversion factors in terms of kg of CO_2 per vehicle is used for distance travelled, and kg of emissions per tonne-km is used for transported cargo in tonnes. The following equation proposes an example for calculating CO_2 emissions of certain transportation modes, where the volume of the transportation, V, (in tonnes) is multiplied with the average transportation distance, D, (in km) and the average CO_2-emission factor per tonne-km, F (Psaraftis 2016):

$$\boldsymbol{Emissions = V \cdot D \cdot F}$$

Conversion factors require data on activity level by vehicle type, which may be obtained from a company's records, and additional conversion tables provided by governments enables companies to convert their road freight activity levels into carbon footprint. Conversion factors listed in a conversion table demonstrates the differences in GHG emissions, and that for each category of vehicle (either articulated or rigid), the higher the gross vehicle weight (GVW), the higher the emissions per vehicle-km but the lower the emissions per tonne-km. Therefore, using fewer, heavier vehicles (HGV) is better for the environment than more, lighter vehicles (LGV) (A. McKinnon et al. 2015). Utilizing on-board sensors and traffic measurements to monitor the emissions of a vehicle is an effective method to using transportation activity modelling and obtain accurate data on transportation emissions and emission factors. In real-life traffic settings, tunnels equipped with sensors are frequently used to evaluate emissions as they prevent measurement errors caused by meteorological factors. In addition, tunnel studies provide the benefit of being able to survey the emissions of a group of vehicles, which can be compared to the results achieved for a single vehicle on a dynamometer. This comprehensive approach leads to more reliable data and enables more accurate evaluations of emission levels (Colberg, Tona, Stahel, et al. 2005).

Similar to the top-down approach, uncertainties in the bottom-up approach to estimating transportation emissions arise due to the varying factors that influence the environmental impact of different modes of transportation. Differences in weight loading factors, pre-trips and post-trips in intermodal transport, different travel distances for different transport modes, loading and unloading actions, and energy consumption in non-driving conditions all contribute to the complexity of assessing the environmental impact of transportation (Kolb and Wacker 1995). Variations in vehicle and engine characteristics, fuel consumption, traffic conditions, driver behaviour, and operating profiles for different modes of transportation are also to be considered. Thus, accurate and reliable evaluation of transportation emissions requires a thorough method that considers all relevant factors and their interactions (Psaraftis 2016)

2.5 Key emissions quantification concepts and factors

WTW, WTT, and TTW

One of the key measurement methods applied to assess the environmental impact of freight transportation is the Well-to-Wheel (WTW) analysis, which depicts the total climate impact of fuel use by measuring produced GHG emissions and energy consumption of transportation processes. This approach considers emissions from the fuel life cycle and is based on the broader framework of Life Cycle Assessment (LCA), excluding emissions and energy involved in vehicles, end of life aspects, or building facilities (EC 2016; Smart Freight Centre 2019). The WTW approach consists of three components, dividing the total energy consumption into two parts:

- **Well-to-Wheel (WTW)** monitors energy use and related emissions outputs across the entire supply chain. It encompasses the total energy process, from fuel or electricity production, through distribution of energy supply with transportation modes, and final energy consumption during the operation of transport modes. This approach is the summation of Well-to-Tank and Tank-to-Wheel values, i.e. direct and indirect emissions, and accounts for all losses occurring in the upstream chain (Eriksson and Nielsen 2014; Schmied and Knörr 2012).
- **Well-to-Tank (WTT)** includes energy use and production of indirect emissions outputs associated with fuel or energy production. It covers all upstream processes and activities from the source of the energy (the well) to the point of consumption (the vehicle tank), including the phases of energy extraction of raw materials, production and processing of fuel or energy, storage, and distribution. WTT values can vary depending on the region, transportation required to move the fuel to

market, energy source, and method of production, and is reported as Scope 3 in the GHG Protocol (Eriksson and Nielsen 2014; Schmied and Knörr 2012; Smart Freight Centre 2019).

- **Tank-to-Wheel (TTW)** covers the final energy consumption and production of direct emissions outputs associated with vehicle operations. It accounts for the emissions resulting from the evaporation or combustion of the used fuel to power the GHG Protocol Scope 1 activities and Scope 2 electric driven activities (the wheel), and is zero for hydrogen, electricity, biofuels, and fuel cells (Eriksson and Nielsen 2014; Schmied and Knörr 2012; Smart Freight Centre 2019).

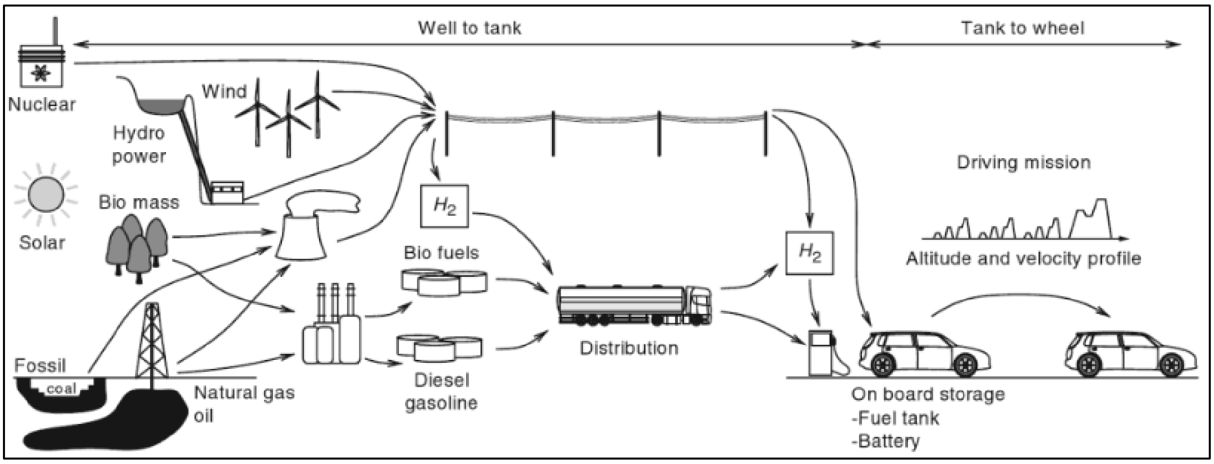


Figure 1: Well-to-Tank and Tank-to-Wheel (Eriksson and Nielsen 2014)

Legs and VOS

In order to calculate the energy consumption and GHG emissions for each section of a transport service, the service must be divided into sections where the item travels on a specific vehicle without changing (Schmied and Knörr 2012). These route sections are known as legs, defined by the start and end points of a particular mode of transport (ETW 2022). The EN 16258 standard requires the use of a Vehicle Operation System (VOS) to quantify and determine the emissions and energy consumption for each leg. VOS refers to the round-trip of a vehicle while transporting goods on a particular section of the route, consisting of vehicle movements related to a specific type of vehicle, route, leg, or even the entire network relevant to the transport section. In addition, VOS provides a basis for computing CO_2 emissions from transport activities, and by computing the energy consumption and emissions at larger network levels, average characteristic values such as

GHG emissions per tonne-kilometre can be calculated and allocated to individual consignments (Schmied and Knörr 2012; Auvinen et al. 2014).

CO_2 equivalents and global warming potential

Carbon dioxide equivalent (CO_2e) is a universal conversion unit used to express the global warming impact of GHGs in relation to carbon dioxide. The CO_2e value allows for a standardized measurement and comparison of the environmental impact of various greenhouse gases using the standard reference of CO_2, and are calculated by multiplying the mass of a greenhouse gas by their global warming potential (GWP) (Defra 2013; Delft 2014; A. McKinnon et al. 2015). The GWP determines the radiative force degree or impact of harm to the atmosphere caused by one unit of a specific GHG in relation to one unit of CO_2, and a higher GWP indicates a greater contribution of the gas to global warming (Schmied and Knörr 2012; Defra 2013). For example, methane has a GWP of 25, indicating that one gram of methane contributes 25 times more to global warming than one gram of CO_2 (Delft 2014).

2.6 Databases, standards, guidelines, and frameworks for measuring emissions

There are many approaches for companies to measure and report their emissions and carbon footprint from transport and other activities, and often these include the use of various carbon footprint methodologies, databases (databanks or data inventory), standards, guidelines, and frameworks. In recent years, organisations have issued guidelines and frameworks for quantifying greenhouse gas emissions from freight transport operations, seeking transparent, precise, and comparable calculations to assess supply chain emissions and carbon accounting (Wild 2021). However, the absence of a universally accepted global standard for product or corporate carbon footprint calculation hinders the comparison of supply chain environmental performance and the identification of best practices. Transport operators, logistics providers, shippers, and others require a unified CO_2 calculation standard. At present, a mix of state-supported, association-developed, research-backed, regional, and transport mode specific standards exist, creating accuracy and compatibility challenges (Kellner and Schneiderbauer 2019).

Emission databases collect emission data from households, companies, and countries to monitor, store and control the development of emissions, reflecting evolving environmental policies. The databases and projects are initiated by worldwide institutions (e.g., EU, UK, US), organisations (e.g., Green Freight Transport), and private entities. Notable EU database projects include EX-TREMIS (EXploring non road TRansport EMISsion in Europe) for non-road transport and with data from EUROSTAT (Schrooten et al. 2009), and HBEFA (Handbook of Emission Factors for Road Traffic) for road transport and simulation of emissions factors from traffic situations, published by the German Federal Environmental Agency (Hausberger et al. 2003). HBEFA is an enhanced version of EU's COPERT (COmputer Programme to calculate Emissions from Road Transport), a partially related ARTEMIS project for creating emission factors (Giannouli et al. 2006). The ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) project is an extension of HBEFA with new measurements and methodology and collects emission data from all EU transport modes (André et al. 2008). Globally, EDGAR (Emissions Database for Global Atmospheric Research) provides comprehensive greenhouse gas and air pollution emission estimates, employing IPCC methodology and international statistics (EC 2023a).

A standard is a consensus-built technical document that serves as a guideline, definition, or rule for a repeatable method for a specific process, product, service, or material agreed upon by all interested stakeholders. Standardisation benefits all parties by enhancing product quality, safety, and cost-effectiveness (CEN c2023). Presently, the European Norm EN 16258 is the only official and international multimodal supply chain standard for transport emission calculations, however, there is no globally accepted standard (Wild 2021).

2.6.1 EN 16258

In 2012, the European Committee for Standardization (CEN) introduced EN 16258, a unified methodology with provided guidelines, principles, allocation rules, definitions, system boundaries and data recommendations for accurate and credible declarations for quantifying energy consumption and GHG emissions in passengers and freight transport services (EN16258, 2012). The development of EN 16258 was prompted by France's plan to require transport operators to disclose their produced CO2 emissions by freight and passenger transport services to customers, using a methodology similar to the European standard (effective October 2013). However, differences between the two, including distinct conversion factors, makes them incompatible for simultaneous use (ETW 2022).

EN 16258 outlines a two-step approach for calculating emissions on shipment level. The first step involves allocating consumption and calculating total volume GHG emissions from all transport operations based on the vehicle operating system (VOS, including collection, delivery, and empty trips, and translating fuel consumption into GHG emissions with emission conversion factors. Patterns of consumption include driver behaviour, vehicle design, road conditions, and other factors effecting fuel consumption. The second step estimates the GHG emissions per single shipments based on the calculated quantity consumed. While EN 16258 allows different allocation units like distance, mass, or volume, a 2016 study recommends using only distance due to its balance between fairness, accuracy, and causality (Kellner 2016, 565-574). The standard incorporates the well-to-wheel (WTW) approach, accounting for direct emissions during vehicle operations and indirect fuel supply emissions from raw material to distribution. It provides detailed emission factors for common fuels, however, it offers flexibility in data sources and estimation methods and leaves much interpretation to the user (Grönman et al. 2018).

Four methods are defined by EN 16258 for calculating transport emissions. The first method is measuring individual transport emissions, which is preferred but data invasive. In addition, the use of subcontractors makes it challenging because of unavailable or low quality of data, and implementation requires significant personnel and financial resources for transport management systems and vehicle data interfaces. The second method assesses the average fuel usage of routes or vehicles; however, it shares similar subcontractor issues as the first method. When it is not possible to conduct methods one or two, the third method uses the average value of the fleets of the partner, subcontractor, and own, with limited data quality. The fourth method is the most used and employs predetermined values based on tonne kilometres, provided by various reporting guidelines and tools. Although it is the most practical alternative, investments in new driver and vehicle efficiency have little effect on the results and makes it inaccurate (Hülemeyer and Schoeder 2019).

ISO (International Organization for Standardization), a non-governmental, independent international association, provides voluntary standards and specifications for guidance for companies seeking to measure their carbon footprint. These standards, renewed every five years, include ISO 14064-1:2018 for organizational-level greenhouse gas emissions quantification and reporting, ISO 14064-2:2019 for project-level emission reduction quantification, reporting, and monitoring, and ISO 14064-3:2019 for greenhouse gas assertion validation and verification. A recent addition, ISO 14083:2023, is based on the GHG Protocol and EN 16258:2012 and establishes a unified methodology for reporting and quantifying greenhouse gas emissions from freight and passenger transport operation chains (ISO c2023). It has been transferred by CEN as an equivalent European Standard EN ISO 14083:2023, and will replace EN 16258:2012 when it is withdrawn within 2023 (EC 2023b).

The GLEC framework, established by the Global Logistics Emissions Council (GLEC) and Smart Freight Centre (SFC), is a leading and consistent methodology for calculating GHG emissions for logistics and transports operations in global multi-modal supply chains (ETW 2022). This guideline provides guidance on data collection and emissions calculations, offering a standardised approach when primary data is unavailable (Smart Freight Centre 2019). It aligns with EN 16258 and complements the GHG protocol, offering precision in distance measurement and a wide range of emission factors considering various vehicle types, fuels, and regions, for informed choices in sustainable logistics services (Hülemeyer and Schoeder 2019).

2.6.2 GHG protocol

The Greenhouse Gas Protocol (GHG Protocol) is the main internationally standardised framework for measuring and managing GHG emissions from operations in the private and public sectors. Developed in 1998 through a partnership between the Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI), this multi-stakeholder association of governments, nongovernmental organizations (NGOs), and businesses addresses the need for a standardised international system enabling corporations to account and report GHG emissions to achieve a low-emissions global economy. The Protocol encompasses corporate value chains, strategies for mitigating climate change, and include reporting requirements, accounting standards, calculation tools, and sector-specific guidelines for the six main greenhouse gases outlined in the Kyoto Protocol: methane (CH_4), carbon dioxide (CO_2), hydrofluorocarbons (HFCs), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs) (GHG Protocol 2011, 2013, 2023a). The current editions of the various GHG Protocol reporting standards and calculation guidelines were issued from 2004 to 2015, and new updated and revised editions are expected to be released in 2025 following several significant improvements in greenhouse gas accounting and reporting (GHG Protocol 2023b).

Companies generate greenhouse gas emissions through indirect sources from the emissions produced by their products throughout their life cycle and other consumed energy, and directly in their warehouses and offices. The GHG Protocol categorises emissions into three scopes to segment these indirect and direct sources of emissions for businesses, which are endorsed by all methodologies and frameworks and illustrated in the figure below (GHG Protocol 2004, 2013):

Scope 1 addresses the direct greenhouse gas emissions produced from business operations of the reporting company. This includes all emissions originating from fuel combustion or the direct release of greenhouse gases linked to activities and sources under the control or ownership of the company, such as process technologies, boilers, vehicles, and more.

Scope 2 addresses the indirect greenhouse gas emissions associated with the purchase and delivery of electricity and energy services from third-party providers and consumed by the reporting company. This includes emissions from the acquired energy in various forms, such as electricity, heat, process steam, and cooling.

Scope 3 addresses all other indirect greenhouse gas emissions arising from the activities of the reporting company and throughout their value chain, including downstream (waste stream and consumer emissions) for services and products and upstream (supply chain). This scope generally accounts for the highest impact of greenhouse gases from a company, encompassing emissions from purchased operations, outsourced freight transportation and distribution, and compliance with this scope needs cooperation along the entire value chain.

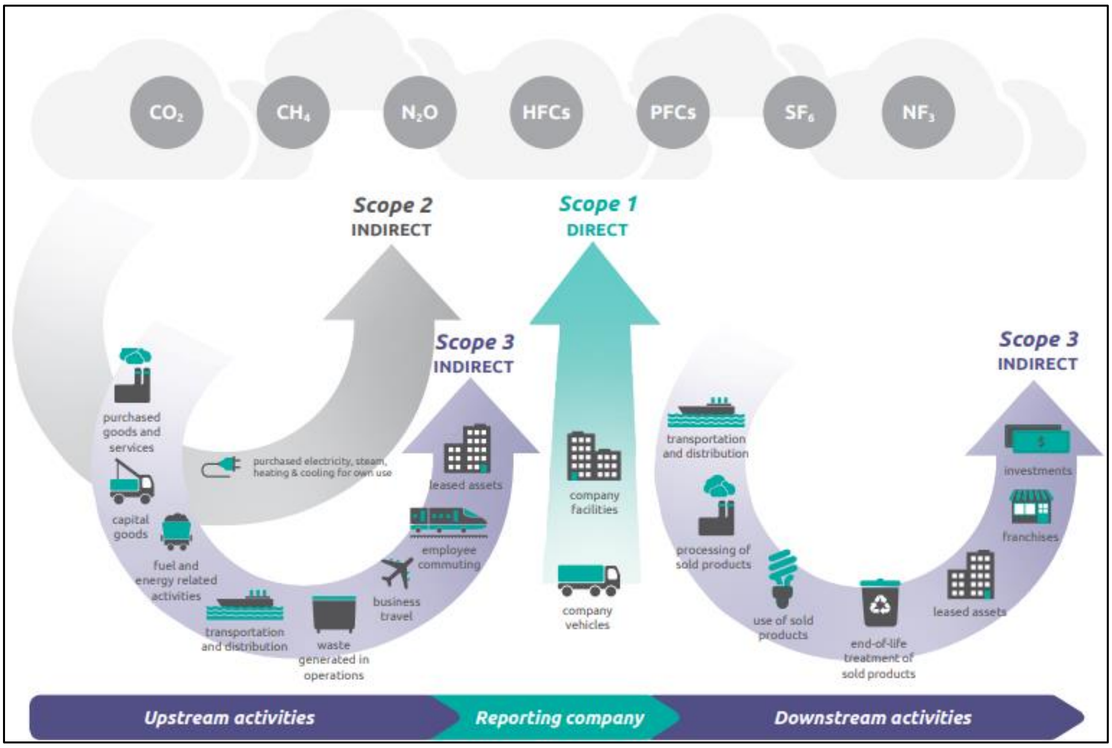


Figure 2: GHG Protocol scopes and emissions (GHG Protocol 2013)

The figure above also illustrates how the Scope 3 Standard divides emissions into 15 categories, which are further organised by downstream emissions (indirect greenhouse gas emissions linked to sold services and products) and upstream emissions (indirect greenhouse gas emissions linked to obtained or purchased services and products). These categories provide a methodical framework for companies to efficiently organise, comprehend, and report on the various scope 3 activities within their corporate value chains. Moreover, they are designed to be distinct entities, ensuring that emissions are not double counted within categories for any reporting company (GHG Protocol 2013).

Categories 4 and 9 are applied when accounting for emissions associated with the transportation and distribution of sold products within Scope 3. Category 4 addresses the upstream emissions originating from third-party distribution and transportation services procured by the reporting company, including outbound and inbound logistics of sold items, and third-party activities between own facilities of the company. The emissions may originate across the value chain, from various modes of transportation activities, including warehouse and distribution storage of procured items. Category 9 addresses the downstream emissions from distribution and transportation of items sold by the reporting company between its processes and final consumer and are not financially covered by the reporting company. This also include storage, retail stores and use of facilities and vehicles not controlled or owned by the reporting company. As depicted in the figure below, the key distinction between these categories lies in the financial responsibility for transportation costs, where category 4 applies when the reporting company pays for the transportation of sold products, whereas category 9 is employed when they do not incur these costs (GHG Protocol 2013).

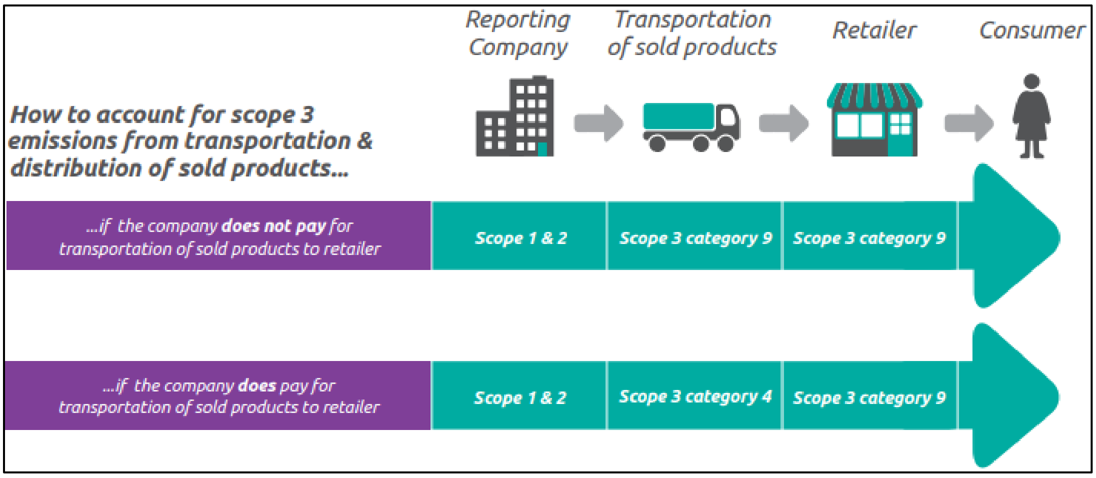


Figure 3: Accounting for emissions from transportation and distribution of sold products (GHG Protocol 2013)

Companies may choose between three approaches when calculating emissions from distribution and transportation within scope 3 for both category 4 and 9. These include the fuel-based approach, which calculates emissions based on fuel consumption and associated emission factors, the distance-based method, which factors in distance, mass, transportation mode, and emissions factor, and the spend-based method, which considers expenditure on different modes of business travel transport and employs secondary input-output emission factors. The reporting company may require collaboration throughout its value chain to collect actual data essential for accurate calculations, including distance travelled, purchased goods volumes, fuel emissions factors, and other essential metrics (GHG Protocol 2013).

The GHG Protocol define several key principles for the reporting and accounting of Scope 3 inventory of GHG emissions of an organisation. These include relevance (determined by user needs), completeness (linked to relevance), consistency (ensuring comparability of methods and reliability), transparency (disclosing assumptions, results, reproducibility and verifiability), and accuracy (avoiding uncertainties and systematic deviations) (GHG Protocol 2011). Notably, conversion factors wield substantial impact on emission data, as demonstrated by a case study involving a single product shipment from Eastern Asia to Sweden. The choice of method could lead to emissions differing by as much as 129% (A.C. McKinnon 2010).

2.7 Carbon footprint calculators

In recent years, carbon footprint calculators have emerged as an essential tool for local and international organisations in assessing and estimating GHG emissions due to growing concern over climate change and the enforcement of regulations, as well as for providing information leading to public awareness, policy and behavioural changes (Padgett et al. 2008; Weigel, Southworth, and Meyer 2010). Developed by private enterprises, government agencies, and environmental non-governmental organisations, these calculators include a wide range of instruments, software algorithms, tools, and other applications aimed at calculating the carbon footprint of logistics activities throughout the supply chain. There are two main categories of carbon footprint calculations tools: Publicly accessible tools, such as EcoTransIT World and NTM, apply to all modes of transport and allow for the modification of various parameters of empty trips, load factor, and more. The other category includes company-specific tools that are developed for specific organisations and may be commercially available to third parties or as an additional service to their customers (Auvinen et al. 2014).

While there are numerous online carbon footprint calculators available, they primarily focus on estimating emissions related to passenger transport alternatives, with fewer options specifically designed for freight transport due to inherent complexities and dimensions. The level of calculation used by carbon footprint calculators determines the required input data for modelling of a logistical service (Delft 2014). In example, key user inputs for calculating GHG emissions from road freight include the emission standard, vehicle type, transport distance, and load weight (Elhedhli and Merrick 2012). However, the range of input and output options provided by freight calculators vary depending on whether they are accessed for free or through a paid service, and with limited outputs to fuel and CO_2 emissions. Furthermore, because there are no standard practices or models, these calculators vary significantly in their methodology and results, despite using the same input (Padgett et al. 2008; Kenny and Gray 2009; Birnik 2013; Mulrow et al. 2019; Harangozo and Szigeti 2017).

The following two carbon footprint calculators have been selected for further research based on their availability and relevance towards measuring emissions from freight transport.

2.7.1 The EcoTransIT Calculation Tool

EcoTransIT World (Ecological Transport Information Tool, hereby ETW) is an independent industry-driven and macroscopic emission model designed to quantify the carbon footprint of freight transport. As a free internet application, the tool provides a comprehensive view of the worldwide environmental impact of freight transport for any route and transport mode, surpassing individual shipment assessments and enabling the analysis and comparison of different transport chains to identify the most environmentally friendly options (ETW 2022). The project for developing this tool was established in 1998 by five large European railway companies, and the first version published in 2003 had a regional focus limited to Europe (Psaraftis 2016). In 2010, a new edition of the tool was released with an expanded worldwide scale, introducing EcoTransIT World. The new edition added extensions for routing logistics and information on environmental impacts for all transport modes, including sea and air transport, and updated methodology to incorporate new data, sources, and knowledge, considering the requirements of the European standard EN 16258:2012. IVE Hannover has developed the internet version of ETW and integrated a route planner for all transport modes, whereas the independent scientific institutes of INFRAS Berne, ifeu Heidelberg and Fraunhofer IML Dortmund are providers of the default values, input, and methodology for ecological assessment of transport chains (ETW 2022).

The free online application of ETW provides users with two levels of input details: a "*standard*" mode for a limited and rough estimate, and an "*extended*" mode for a more precise calculation based on available shipment information. With the extended version users can adjust all relevant parameters to their individual needs and data, like load factor, distance, route characteristics, vehicle size, empty trips, and engine type. ETW offers licensed Business Solutions adapted for professional users, delivering customised interfaces and solutions based on individual customers' real operational data and requirements. The platform includes standardized interfaces (API) that enable automatic emission calculations for extensive transport chains, delivered as Software-as-a-Service. Moreover, IVE mbH offers consultation projects to calculate, analyse, and present customer-specific transports. By utilizing the Business Solutions, companies can efficiently fill their corporate data warehouses with all the necessary information for regional inventories, provide carbon accounting benchmarks, generate specific environmental reports, or establish carbon reporting (ETW 2022).

The ETW emission calculation tool meets the terms of the global GLEC framework, ISO 1483:2023 and the Well-to-Wheel (WTW) GHG emissions as per the GHG Protocol Corporate Value Chain Accounting and Reporting Standard. Its methodology follows the EN 16258 standard "*Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services*", which follows a two-step process of calculating the final energy consumption for each leg of the transport service using Vehicle Operation System (VOS), and then converting these values to standardised energy consumption and CO_2 equivalent emissions based on Tank-to-Wheels (TTW) and WTW measurements with conversion factors. While the internet tool provides results based on only EN 16258 conversion factors, the Business Solutions can also incorporate conversion factors from the French decree to align with French regulations. An important disclaimer regarding the latest methodology available on their website (2023) is that the current calculation methods of ETW follow new applied conversion factors from the ISO 14083:2023 (new methodology version available within 2023) and are no longer compliant with EN 16258:2012 (ETW 2022).

ETW uses an energy-based bottom-up approach to calculate emissions, which relies on the associated fuel usage and energy consumed, in contrast to the common top-down method where emissions are determined by multiplying gCO_2e/tkm by the distance and freight weight. The bottom-up approach involves simulating the entire transport system, encompassing parameters such as road type, vehicle class with specific characteristics, load factor, and the fuel. This approach ensures the versability of the tool and futureproofing by requiring only a single parameter in the calculation workflow to be adjusted to map new vehicle technology or fuel types. The calculation workflow is divided into four stages (ETW 2022, 2023):

1. **Route determination**: Utilizing broad transport-specific GIS data networks and an internal routing algorithm to determine the route.
2. **Route subdivision**: Splitting the route into calculation sections based on changes in emission-relevant parameters, including road type for trucks, ferries for trucks

and trains, country changes for trucks and trains (particularly relevant for electricity mixes and biofuel shares), and ECA or non-ECA zones for sea ships.

3. **Calculation of emissions and energy for each section**: Calculating emission curves, energy requirements, and fuel consumption based on vehicle attributes (emission class and type), as well as route attributes for each section. Calculation involves various parameters such as load factor, freight weight, fuel type and biofuel share, distance per section, emission factors based on vehicle attributes, and fuel consumption.
4. **Output of results and summation**: Combining the findings from all sections to obtain total output for distances, GHG, air pollutants, energy consumption, external costs, and transport parameters used. Optional outputs may include fuel type and emissions per country split.

Numerous calculation parameters and predefined standard values of the ETW tool allows for detailed, customer-specific transport modelling, providing a high level of flexibility of calculation details to specific and individual requirements. The transport details contain gross weight in tonnes, containers (TEU, FEU) or pallets, while the input data include destinations, origins, and waypoints (coordinates), mode of transport (vehicle types), and transport description (fuel type, load factor, etc). The calculation is described in the workflow above, and the calculation results from the environmental parameters are of emissions as WTT and TTW (CO_2, CO_{2eq}, NO_X, SO_X, PM, NMHC), external costs related to CO_2eq, accidents, noise, and environmental pollutants (ETW 2023).

The sources for each transport mode are the following:

Road: In Europe, the "Handbook emission factors for road transport" (HBEFA) (INFRAS 2019) serves as the primary source for vehicle emission factors and final energy consumption, specifically for trucks adhering to EU emission limits and class standards, while in the United States, the MOVES model based on EPA standards and American data (EPA 2014) is utilized. The energy and fuel consumptions are dependent on the driving pattern, different road gradients for each country, and the load factor, which are influenced and modelled by the HBEFA (ETW 2022).

Sea: The emission factors for sea transport in the ETW model primarily rely on the findings of the Fourth Greenhouse Gas study conducted by the IMO in 2020. A bottom-up approach based on technical data and activity from IMO data, IPCC Guidelines for

National Greenhouse Gas Inventories, US Environmental Protection Agency (EPA) and Lloyd vessel inventory of 600 bulk carriers and 4000 containers is further used to derive emission factors and fuel consumption for size classes and ship categories. Liquid bulk carriers, dry bulk carriers, container carriers, Roll-on-Roll-off vessels, and general cargo vessels are some of the vessel types for which underlying emission factors have been developed, whilst ferry services are extensions of the road network (ETW 2022). Separate emission factors have been developed for sulphur emission control areas (SECAs), such as the North Sea and Baltic Sea, and emissions from ships leaving the SECA will reflect both non-SECA and SECA emissions (Hjelle 2012).

Rail: Energy and emissions calculations for rail transport primarily rely on the total train's energy consumption, which is determined by the gross tonne weight of the train and the ratio of gross tonne weight to net-tonne weight. ETW uses TTW energy functions that have been verified using average values from various European railways, with three gradient levels added for countries with diverse topologies. The EX-TREMIS study is acknowledged as the "official" dataset for Europe, and the UIC data base, Railion (DB Cargo) and Ifeu provides additional empirical data for train energy consumption statistics of European railway companies. The United States, Canada, and China have their own sets of statistics and studies that offer insights into the average energy consumption of freight trains in these respective countries (ETW 2022).

Air: The flight distance influences the specific TTW emissions and energy consumption of air cargo transportation due to differences in emissions and energy requirements throughout various flight stages. The fuel consumption data for various aircraft types is derived from the "Small Emitters Tool", developed by EUROCONTROL on behalf of the European Commission and the European Emissions Trading Scheme (ETS), and collects yearly updated statistical data on actual fuel consumption for a wide range of aircraft types. The primarily used data source assumes a linear relationship between flight distance and fuel consumption. In cases with aircraft without directly measured fuel-burn data, the energy consumption of other aircraft types within the same family is used and adjusted using a correction factor based on the maximum take-off weight (MTOW) ratio or the EMEP/EEA Air Pollutant Emission Inventory Guidebook (formerly EMEP CORINAIR). NMHC, PM and NO_X emissions are calculated using the EMEP/EEA guidebook, whereas fuel consumption directly generates SO_X, CO_2, and CO_2 equivalents (ETW 2022).

2.7.2 The NTM Calculation Tool

The Network for Transport Measures (NTM) is a Swedish non-profit organisation founded in 1993 by a diverse group of Swedish transportation organisations and institutions and works without regard to any partial interests to develop standardised data and calculation methods to determine the environmental and energy performances of various transportation modes. The methodology and macroscopic model developed by NTM primarily serve market actors of transport services, allowing them to assess the environmental impact of their own transportation activities and individual carbon footprint (NTM 2023a).

In 1998, NTM introduced its first website, and some years later the company released the first version of their environmental calculator, NTMCalc 1.0, which uses a series of emission factors for freight movements by air, rail, sea, and road, and split by power source and vehicle type attained from transport operators (A. McKinnon and Piecyk 2010; NTM 2023a). The most recent free version, NTMCalc. 4.0 from 2015, considers nine out of twelve contributing elements in its calculations, including load factors, distance, mode of transportation, road type (highway, rural or urban), topography, and positioning (NTM 2023a). Cargo specifications, number of stops, speed, and empty runs are not directly accounted for, however, emissions from empty runs, which are included in the master data, can be computed independently and added later (Dehdari, Wlcek, and Furmans 2023). NTM has developed "product category rules" for transport, and their most recent calculation methodology is compatible with ISO 14083 and EN 16258 standard for calculating energy use and GHG emissions for transport (NTM 2023a).

While NTMCalc 5.0 was released in 2021 for members only, version 4.0 is currently available online with a basic and advanced version, with feature categories of vehicle types and classes, calculation models, outputs, parameter settings, transport chain, routing, reports, and support (NTM 2023a, 2023b). The basic version is free, fully functional, and accessible for public use, with a smaller dataset and certain limits in calculations. The calculation parameters have default settings, with some user interactions deactivated. The freight advanced version is exclusively accessible for members and offers additional options for input, output, modifications of settings, and precise calculations (NTM 2023b).

The general calculation workflow of this model involves road conditions (represented by varying fuel consumption rates), load, distance, and transport mode, and can be simplified into two key steps (Niu et al. 2023):

1. Calculating fuel consumption per unit distance by combining various load variables and fuel consumption rates.
2. Total carbon emissions are calculated by multiplying the distance travelled, the fuel consumption per unit distance, and carbon emission factor.

The system presents preloaded data for all input fields and parameter settings in the online webtool, except for fuel consumption, distance, and shipment size. Depending on the basic or advanced versions, the emission report includes outputs for CO_2, CO_2 equivalents, SO_2, NO_X, N_2O, CH_4, HC, and PM. The output for the energy report is primary energy use, fuel consumption, and electricity consumption whenever it is applicable. In addition, the calculations incorporate the life cycle phases of WTW by combining WTT and TTW, and each of the phases are accounted for separately in the result report by each transport activity (NTM 2023a).

The sources for each transport mode are the following:

Road: NTMCalc calculates pollutant emission and fuel consumption factors for four types of road vehicles: passenger cars, heavy duty buses, light duty trucks, and heavy-duty trucks, which are further divided into sub-groups of vehicle sizes with related data on road gradient, fuels, traffic, and emission standards. The European Road Emission model HBEFA 3.1 (Euro 5 and 6 from version 3.2) is the source of all fuel consumptions and emission factors for road vehicles. The fuel consumption for road transport is calculated by multiplying the distance by the distance-related fuel usage that is aligned with the load factor, road type, and vehicle, and pollutant emissions are computed by multiplying fuel emission factors and total fuel usage (NTM 2023a).

Sea: The environmental performance of various ship types and sizes, including containers, general cargo, and tankers, is measured by the calculator. It applies the methodology set by The International Maritime Organization (IMO) for calculating the CO_2 emissions per tonne-km for ship types based on their deadweight (dwt), which represents the cargo capacity. However, the payload, or maximum cargo capacity, is less than the dwt in practice, and both the fill-factor and load capacity utilization (LCU) should be included. In addition, the load of a ship will affect the fuel consumption (measured in mass of fuel per distance), as a vessel carrying a heavier load will sink deeper and face greater water resistance. Emission factors for ships are presented in mass of fuel burned per mass of emission, and the factors used are categorised per types of fuel, ship, and engine (NTM 2023a).

Rail: In the early stages of developing the environmental calculations for rail transport, NTM investigated several methods and models for rail, however, they did not find any that met their specific criteria. The International Union of Railways (UIC) has the complete statistics database on train energy use, still it is confidential and inaccessible. Fortunately, this database was analysed by EcoTransIT, which generated a rough correlation between the amount of electricity needed for momentum and train weight and was later used in NTMCalc 3.0. For electric trains, NTM uses a production-specific method to calculate the electricity production and electricity usage of a train (NTM 2023a).

Air: The emissions produced in air transport are primarily determined by the combustion process of the jet engine, and the scale and nature of the substances released depend on the amount of thrust required by the engine for each flight phases. The efficiency of aviation is greatly influenced by the load factor, and additional weight has a significant (non-linear) impact on the energy required for transportation. NTMCalc incorporates three types of aircraft in its database: pure passenger airliners, pure cargo freighters, and combined freight and passenger aircraft, and the aircraft emissions database is developed based on calculations using the commercial program PIANO for set load factors. The user inputs include weight and distance for payload, and the emission factors are categorized into two groups: Variable Emission Factors (VEF) and Constant Emission Factors (CEF), and the overall emissions are equal to the sum of CEF and VEF (multiplied by the distance flown) (NTM 2023a).

3.0 Case description

3.1 The Company

Glamox AS is a Norwegian industrial group with headquarters in Molde, Norway, that creates, produces, and sells professional lightning solutions on a global scale (Glamox c2022a). The history of the company dates to 1947 when the Norwegian scientist, inventor and civil engineer, Birger Hatlebakk, experimented with electrochemical processes and surface treatment of aluminium. He developed the method of *glamoxation* (derived from the Norwegian words *glatt-matt-oxydert*) and founded Glamox after discovering how this process could be used to produce efficient aluminium reflectors for powerful luminaires. The company built a factory in Molde, Hatlebakk's hometown, and following their expansions of product development and sales volumes throughout the next decades, they continued to establish sales organisations in the northern countries and factories and production facilities globally. Today, Glamox are owners of several lightning brands and distributes light fittings for industry, shipping, oil operations and commercial buildings from factories in Norway, Germany, Estonia, China, and Canada (Glamox c2022c).

3.2 The background for the company case study

Glamox has a mission to "*provide sustainable lighting solutions that improve the performance and well-being of people*" and their ambition is to be a sustainability leader in the industry of lighting solutions (Glamox c2022d). The company is constantly working to decrease their environmental impact of their products and operations and reduce their emissions of greenhouse gases. To achieve this, they have committed to the Science Based Targets initiative (SBTi), a worldwide partnership between multiple environmental organisations, and is implementing sustainability measures by measuring the existing emissions *across their entire value chain* (Glamox c2022b). In addition, Glamox is a Signatory and Participant to the UN Global Compact and supports the UN Sustainable Development Goals (SDGs) (Glamox 2021).

In collaboration with experts and key stakeholders the company has developed a sustainability strategy around four pillars, directly built on their mission and values, and supporting the SDGs (Glamox 2021):

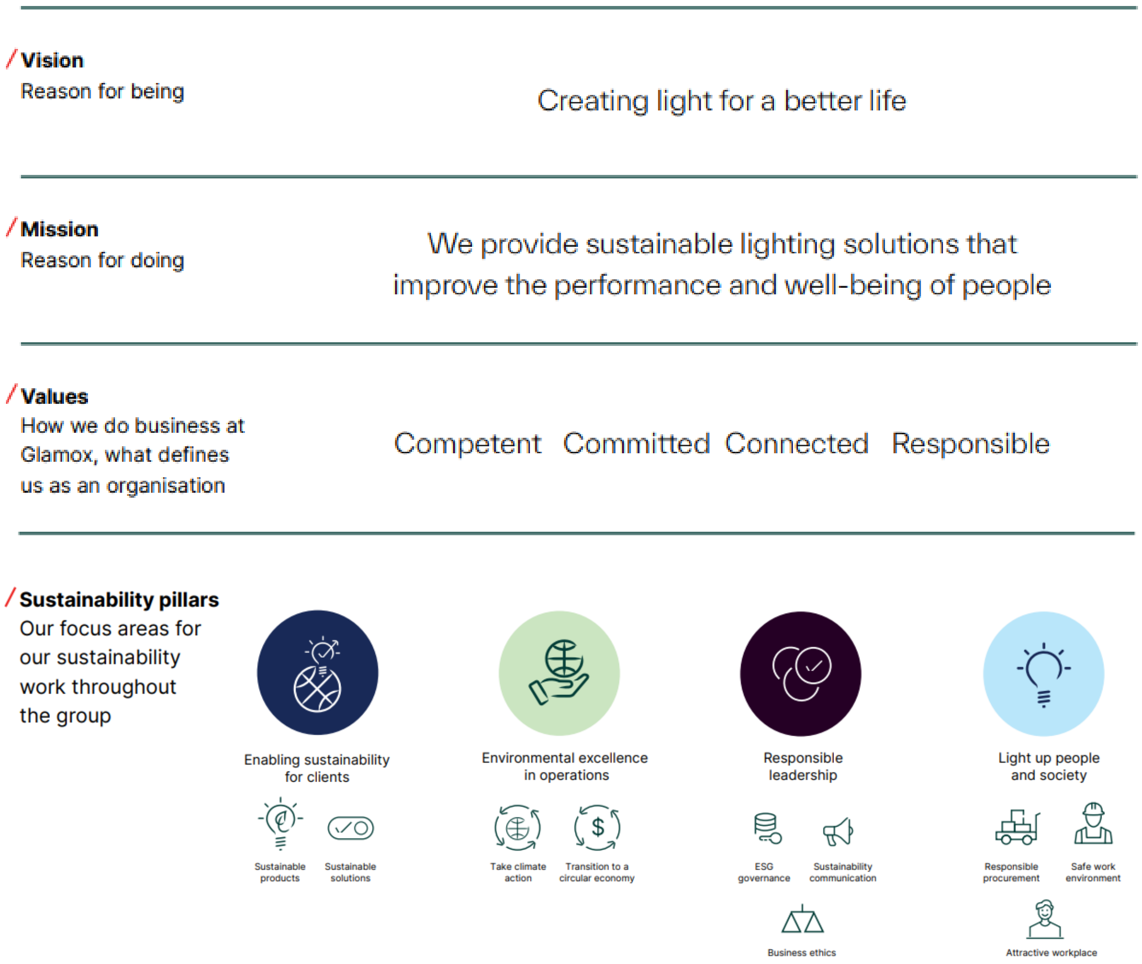


Figure 4: Four pillars defining the sustainability strategy of Glamox (Glamox 2021).

In this case study, the area of interest is the pillar ***Environmental excellence in operations***, with a specific focus on ***taking climate action***. Glamox seeks to reduce and minimize the environmental impact and footprint of the company, which subsequently effects the footprint of their *customer*. Their goal is to become a net zero company by 2030. This involves examining the *full life cycle* of the products to ensure that the consumption of energy is lowered, and emissions are reduced throughout the value chain to product end-of-life. The following figure displays the value chain of Glamox, which identifies the various parts of the supply chain that must be investigated for existing emissions (Glamox 2021):

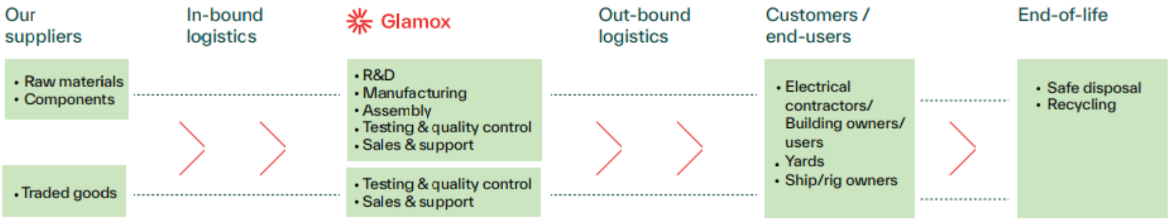


Figure 5: The value chain of Glamox (Glamox 2021).

The many parts of the value chain of Glamox are managed by either Glamox or outsourced to other companies. Glamox has a direct link to their factories and can initiate change for sustainability throughout the phases of production and manufacturing by altering the product designs to ***transition to a circular economy*** (part of the pillar *Environmental excellence in operations*). For instance, the company has taken action to implement changes towards sustainability by certifying their production units in Norway, Sweden, the UK, and Poland in accordance with ISO 14001, and Estonia with ISO 50001 (Glamox 2021).

In relation to ***taking climate action***, the company aims to contribute to lower the environmental impact through several objectives, and one of these is "***as far as possible, use environmentally efficient transport solutions***" (Glamox 2021). This objective may be challenging because the out-bound transport logistics of the company is outsourced to other transportation companies, such as DB Schenker, DHL, Kuehne + Nagel, and more. Furthermore, this means Glamox does not have authority to directly implement any changes towards sustainability in these transportation companies. Instead, Glamox is collecting emissions data from all the transportation companies they use as an attempt to map the transport emissions of the company. However, the collected data reveals that the various transportation companies calculate emissions differently, and with missing numbers the statistics does not give a proper presentation of the transport emissions of the company. The results further indicate the many possibilities to measure transport emissions, by example how they are measured, from where to measure (well-to-wheel, well-to-tank, tank-to-wheel), different variables and parameters, and many other factors. Moreover, some transportation companies have not provided emissions data and Glamox has therefore used their own calculation tools to measure the emissions of these companies.

4.0 Methodology

4.1 Scientific research

Research is a dynamic process aimed at addressing previously unanswered questions to obtain reliable solutions, and it entails a comprehensive exploration of a subject to uncover new insights or attain a new comprehension (Devi 2017). The term "scientific" refers to study that adds to the body of scientific knowledge and follows the scientific process, and there are three primary categories of this research term: descriptive, exploratory, and explanatory. Descriptive research carefully observes and identifies issues within specific conditions, facilitating the examination of variations within established environments and analyses the when, what, and where of a phenomenon (Siedlecki 2020). Exploratory research aims to explore the magnitude of a phenomenon, uncover new insights and address underexplored or understudied problems (Swedberg 2020). Explanatory research delves into observed problems or phenomenon to identify underlying causes and reasons, seeking a deeper understanding of established events beyond a topic and answering questions of how and why (Nayak and Singh 2021).

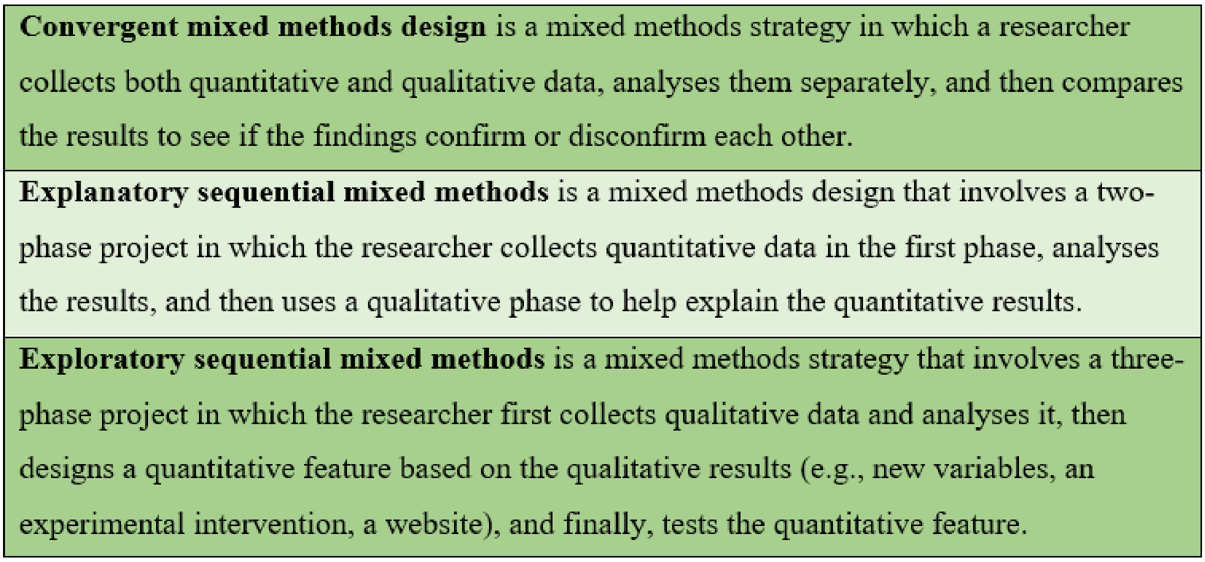
The selected scientific research approach for this thesis aligns with explanatory research. It seeks to explain the complexities of CO_2 calculators, particularly for freight operations, and understand the theory and underlaying mechanisms of *how* they work and *how* they are used. With the variety of CO_2 calculators on the market, including both commercial and private options, this research recognises the potential for significant variations in calculation methods and outcome despite similar inputs, motivating an investigation of the causal factors driving this variability. Furthermore, the thesis seeks to find out the drivers behind *why* companies measure their emissions and explain their use of CO_2 calculators.

4.2 Research design

A research design is the structured and methodical plan that guides the research to attain valid objectives (Asenahabi 2019). It divides into three categories: qualitative, quantitative, and mixed methods. Qualitative research processes non-numerical data and gathers details and insight of complex subjects from the experience and opinions of participants (Mishra and Alok 2017). Quantitative research focuses on numerical data and modification of observations to describe, explain and summarise data characteristics or predicting outcomes of a phenomena (Sukamolson 2007). Mixed methods research combines both approaches of qualitative and quantitative research designs to enhance empirical understanding of the research. Using mixed methods in research has several advantages, including the complementarity of results between methods, facilitating the development of a method based on results from another, and enhancing the information-seeking process by broadening the scope of inquiry by incorporating different approaches (Molina-Azorin 2016). The selected research design for this thesis is the use of mixed methods, which aligns with the explanatory research approach and involves both quantitative and qualitative research.

4.2.1 Types of mixed method designs

Various academic sources systematically categorise mixed methods using distinct dimensions, often based on the combination of quantitative and qualitative research (Guest and Fleming 2015). Creswell and Creswell (2018) outlines three types of mixed method designs, as described in table 1. In selecting the design, researchers must determine how data from the two methods will be merged, explained, or built, shaping the design of the method, and if the data from each method is to be analysed concurrently (results are brought together) or sequentially (data analysis builds upon another). The mixed method design chosen for this thesis falls under the category of explanatory sequential mixed methods, which is further detailed in the next section.



Convergent mixed methods design is a mixed methods strategy in which a researcher collects both quantitative and qualitative data, analyses them separately, and then compares the results to see if the findings confirm or disconfirm each other.
Explanatory sequential mixed methods is a mixed methods design that involves a two-phase project in which the researcher collects quantitative data in the first phase, analyses the results, and then uses a qualitative phase to help explain the quantitative results.
Exploratory sequential mixed methods is a mixed methods strategy that involves a three-phase project in which the researcher first collects qualitative data and analyses it, then designs a quantitative feature based on the qualitative results (e.g., new variables, an experimental intervention, a website), and finally, tests the quantitative feature.

Table 1: Three Major Design Types (Creswell and Creswell 2018)

4.2.2 Explanatory sequential mixed methods

The explanatory sequential mixed methods design involves a two-phase approach in which the researcher initially conducts quantitative research, analyses the findings, and subsequently uses qualitative research to provide a more in-depth explanation of the quantitative results. The term "explanatory" comes from its detailed explanation of the quantitative data using qualitative data, and it is characterised as "sequential" since the quantitative phase precedes the qualitative phase, typically employed in fields with a significant quantitative emphasis (Creswell and Creswell 2018). The main approach for this thesis has been to first conduct a quantitative research and comparative analysis to examine and provide insight into the performance of the CO_2 calculators, uncover patterns, and compare any variations in their outcomes. This was then complemented by qualitative research to further investigate and understand the contributing factors of the quantitative results.

4.2.3 Explanatory case study with quantitative and qualitative approach

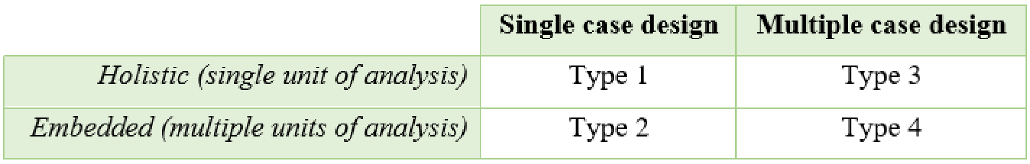
The purpose of explanatory studies is to seek and explain answers to questions of *how* and *why*, while attempting to “*connect the dots*” in the research by finding causal factors and results of the targeted known phenomenon (Nayak and Singh 2021). In this thesis, the division between the quantitative and qualitative research aligns with the aspects of “*how*” and “*why*”. The quantitative research is seeking the answers to *how* companies are measuring their emissions, investigating the methodologies and the use of CO_2 calculators, and assessing the validity, reliability, and replicability of the CO_2 calculators. Meanwhile, the qualitative research is seeking the answers to *why* the companies are measuring their emissions, including their motivation, transparency and the challenges associated with data acquisition.

4.3 Research strategy: Case study

A research strategy is a detailed framework outlining the ways in which a researcher should arrange and facilitate the research, including the plan for sampling, research design, and data collection method. It connects the chosen approach, theoretical foundations, and the methods for data collection and analysis techniques. The employed research method often determines the choice of strategy, such as surveys, experimental, quasi-experimental, case studies, ethnography, grounded theory, and more (Saunders, Lewis, and Thornhill. 2019).

When choosing research strategy, it is essential to ensure that the selected strategy aligns with the research questions and methods. Case study research, a technique used for in-depth analysis of individuals, groups, or complex phenomena, is especially suitable for investigating *how* and *why* questions, as well as unique or intricate issues not easily studied with other methods. Data collection methods typically encompass document analysis, interviews, and observations. The primary objective of case study research is to gain a comprehensive understanding of the subject, fostering theory development or practical guidance. While primarily qualitative, it can also incorporate quantitative methodology (Saunders, Lewis, and Thornhill. 2019).

Case studies can be approached as a single case study or multiple cases studies, where multiple cases are examined using the same research questions (Hammond and Wellington 2012). Table 2 presents four types of basic design, where the single and multiple case designs are further divided into holistic and embedded categories according to the number of units of analysis. *Unit of analysis* describes the level of researched observation or analysis, and imply an organisation, person, event, or group as subjects of the term (Ghauri, Grønhaug, and Strange 2020).



	Single case design	**Multiple case design**
Holistic (single unit of analysis)	Type 1	Type 3
Embedded (multiple units of analysis)	Type 2	Type 4

Table 2: Four types of basic design for case studies (Ghauri, Grønhaug, and Strange 2020)

The research strategy chosen for this thesis is a single company case study with embedded sub-units (or sub-cases) (type 2 design). The case study design supports the core of the research questions for this thesis, *how* and *why*, and the explanatory mixed methods with both quantitative and qualitative approaches. The primary object of this study is a company, Glamox AS, which represents the main unit of analysis, with three participating transportation companies as embedded sub-units. The strategy for the quantitative approach is to use real life numerical data and compare the numbers with available online measuring tools and self-composed calculations, inspired by the findings in the literature. The qualitative approach was conducted with a follow-up questionnaire, interviews, and e-mail correspondence to supplement the quantitative data.

The original concept for this thesis was based on a main quantitative approach, with the plan to create a case comparing the results of CO_2 calculators from three transportation companies and self-composed calculations. The case involved creating a fictitious delivery from the Glamox factory in Molde in two separate transport routes towards two distribution terminals in Europe. To ensure the best results and a basis for comparison, the transportation companies would have similar starting points in terms of input details for goods information, routes, vehicles (preferably only road transport), and no reloading. It was desirable that the transportation companies would generate reports from their advanced and standard calculator versions and provide emission information, methods, background for calculations with equations, detailed descriptions of the sequence of events for their transportation routes, and more. However, it later became evident during the early stages of data collecting that it was not possible to execute this plan due to confidentiality and other reasons. The strategy was then changed to collecting numerical emissions data from the transportation companies and extract examples of deliveries based on specific details, such as routes to specific destinations, high volume and weight, etc. These examples were recreated in the online CO_2 calculators of EcoTransIT and NTMCalc and self-composed calculations, and an evaluation and comparative analysis were conducted along the process for the inputs and outputs. This was then supplemented by qualitative data from a questionnaire and interviews of the transportation companies in the pursuit of the reason behind the missing information and in-depth explanations of the collected data.

4.4 Data collection

The method of collecting data and information for this thesis is based on two main data sources – primary and secondary sources. Primary data is collected by the researcher, employing methodologies suitable for addressing the research problem. Secondary data is information gathered by different researchers, either directly from published or unpublished sources, and has been validated through previous research (Hox and Boeije 2005).

The primary data sources for this thesis are obtained through a questionnaire and interviews during the qualitative phase. The questionnaire was sent to a representative for each of the transportation companies and included open-ended questions regarding the detailed background information of the calculation tools used by the transportation companies, searching the answers for both *how* and *why* the companies calculate their emissions. The additional interviews were conducted between the representative of the transportation company, representative from Glamox, and the author of this thesis, for further explanations and clarifications of the collected numerical company records and any missing information.

The secondary data sources include scientific literature, articles, emissions reports, methodology reports for the calculation tools, company records, and other electronic sources for the theoretical research. In the quantitative phase, secondary quantitative data is the outcome from the emissions calculations, generated from the collected numerical company records from both Glamox and the transportation companies, and by the utilisation of different calculation tools.

4.5 Research quality

There are two main aspects to consider when ensuring the quality, trustworthiness, and credibility of the research: Reliability and validity. Reliability in research is the degree of consistency to which the repeated testing of a property yields the same results. It covers the stability and capability of repeating responses, along with the ability of the investigator in collecting and documenting the provided data precisely. Validity in research refers to the truthfulness and accuracy of scientific discoveries, ensuring that a study accurately represents the existing reality. Two key types of validity are internal, which concerns the extent to which research findings genuinely reflect reality rather than the effect of external variables, and external, which examines the degree of applicability of these reflections across different groups (Brink 1993). There are several ways by which reliability and validity can be achieved in research. Using a variety of data sources creates a chain of evidence that supports the validity of the research, and employing pattern-matching techniques in data analysis contributes to internal validity (Yin 2003). The combination of quantitative and qualitative research methods in data collection and analysis established a foundation with multiple sources when examining the research questions, contributing to the reliability and validity of the thesis.

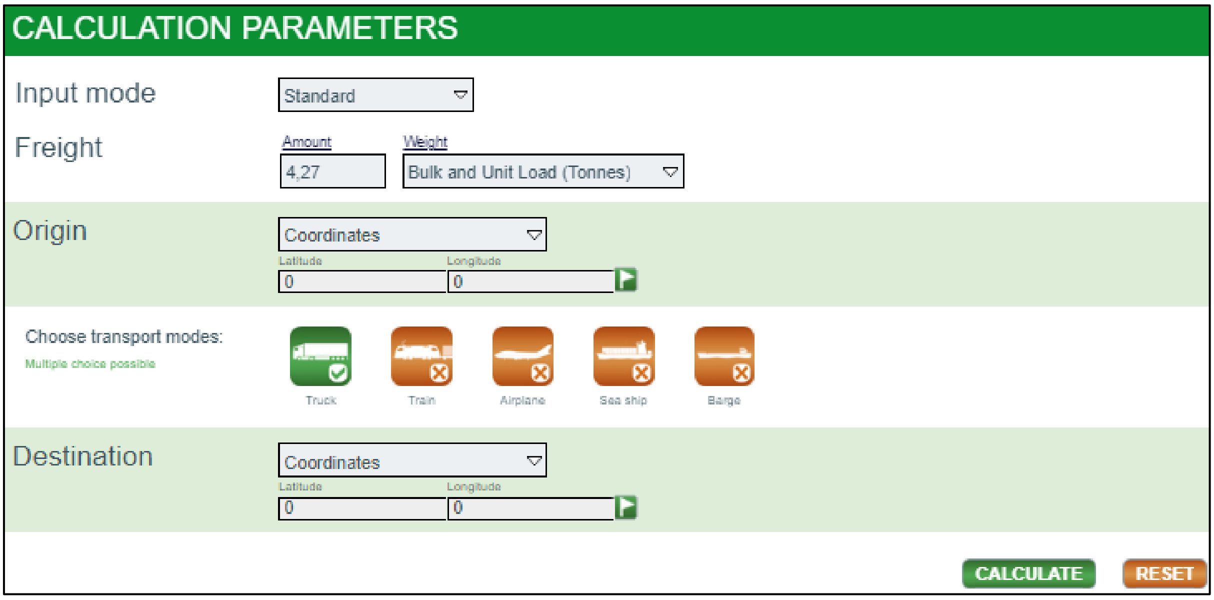
5.0 Results, analysis, and findings

5.1 Creating the cases

Three cases have been created to analyse and illustrate the differences in calculations of carbon footprint emissions. These are set up according to the online CO_2 calculators and their available online versions, which are standard and extended versions for EcoTransIT and Basic for NTMCalc. Input from selected routes and deliveries from collected data will be used as input in the calculators, and the produced output will be compared with the output in the collected data.

Case 1: Standard version (ETW)

The standard version of the emission calculator of EcoTransIT has limited options for input, with only choices for amount, weight, origin, destination, and multiple transport modes, illustrated in a screenshot example below. The selected inputs used for this case were amount in tonnes, road as the only transport mode, and coordinates instead of city districts or postal codes for the outcomes to be more precise.


CALCULATION PARAMETERS

Input mode: Standard

Freight: Amount 4,27; Weight Bulk and Unit Load (Tonnes)

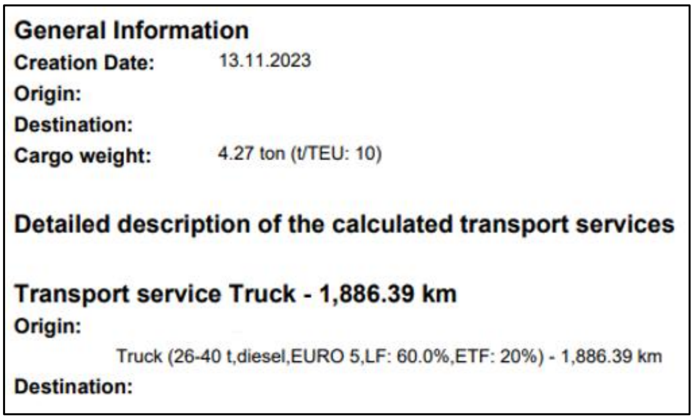
Origin: Coordinates; Latitude 0; Longitude 0

Choose transport modes: Multiple choice possible
Truck ☑
Train ☒
Airplane ☒
Sea ship ☒
Barge ☒

Destination: Coordinates; Latitude 0; Longitude 0

Figure 6: EcoTransIT standard version - Input data

The generated output data report (pdf) included details from the input data and default values unchangeable in the standard version, such as specified vehicle type of 26-40 tonne truck, diesel as fuel, EURO 5 emission standard, 60% load factor and 20% empty trip factor based on average values. In the screenshot below the coordinates for the origin and the destination have been removed due to confidentiality.



General Information

Creation Date: 13.11.2023

Origin:

Destination:

Cargo weight: 4.27 ton (t/TEU: 10)

Detailed description of the calculated transport services

Transport service Truck - 1,886.39 km

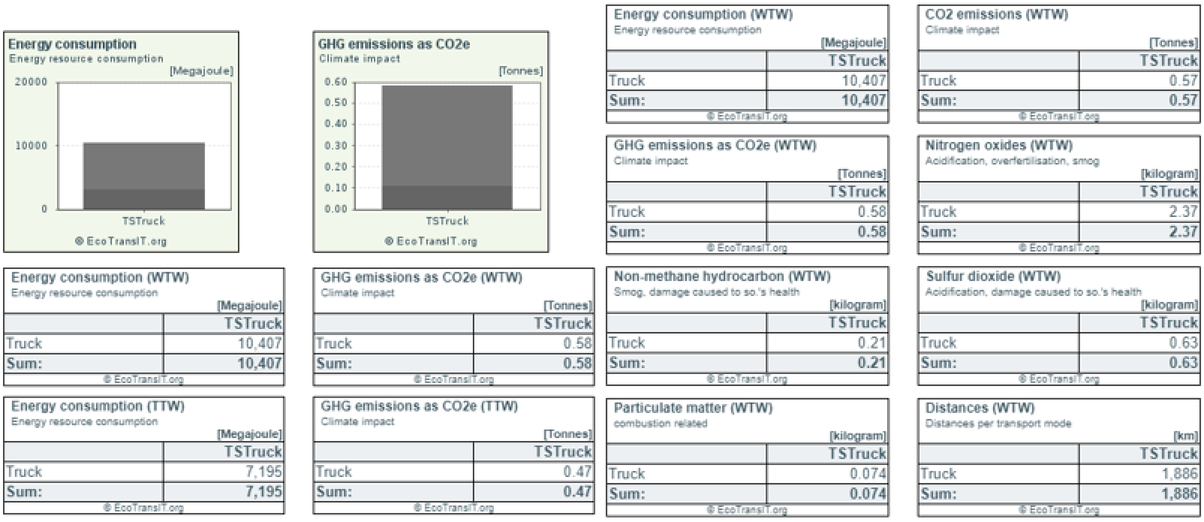
Origin:

Truck (26-40 t,diesel,EURO 5,LF: 60.0%,ETF: 20%) - 1,886.39 km

Destination:

Figure 7: EcoTransIT standard version - Output data

Additional outputs included energy consumption in TTW and WTW in Megajoule (MJ), GHG emissions as CO_2e TTW and WTW in tonnes, CO_2 emissions TTW (in the report) and WTW in tonnes, and sulphur dioxide (SO_2), nitrogen oxides (NOx), non-methane hydrocarbon (NMHC), and particulate matter (PM) in WTW in kg.



Energy consumption (WTW)
Energy resource consumption
[Megajoule]

	TSTruck
Truck	10,407
Sum:	**10,407**

© EcoTransIT.org

CO2 emissions (WTW)
Climate impact
[Tonnes]

	TSTruck
Truck	0.57
Sum:	**0.57**

© EcoTransIT.org

GHG emissions as CO2e (WTW)
Climate impact
[Tonnes]

	TSTruck
Truck	0.58
Sum:	**0.58**

© EcoTransIT.org

Nitrogen oxides (WTW)
Acidification, overfertilisation, smog
[kilogram]

	TSTruck
Truck	2.37
Sum:	**2.37**

© EcoTransIT.org

Energy consumption (WTW)
Energy resource consumption
[Megajoule]

	TSTruck
Truck	10,407
Sum:	**10,407**

© EcoTransIT.org

GHG emissions as CO2e (WTW)
Climate impact
[Tonnes]

	TSTruck
Truck	0.58
Sum:	**0.58**

© EcoTransIT.org

Non-methane hydrocarbon (WTW)
Smog, damage caused to so.'s health
[kilogram]

	TSTruck
Truck	0.21
Sum:	**0.21**

© EcoTransIT.org

Sulfur dioxide (WTW)
Acidification, damage caused to so.'s health
[kilogram]

	TSTruck
Truck	0.63
Sum:	**0.63**

© EcoTransIT.org

Energy consumption (TTW)
Energy resource consumption
[Megajoule]

	TSTruck
Truck	7,195
Sum:	**7,195**

© EcoTransIT.org

GHG emissions as CO2e (TTW)
Climate impact
[Tonnes]

	TSTruck
Truck	0.47
Sum:	**0.47**

© EcoTransIT.org

Particulate matter (WTW)
combustion related
[kilogram]

	TSTruck
Truck	0.074
Sum:	**0.074**

© EcoTransIT.org

Distances (WTW)
Distances per transport mode
[km]

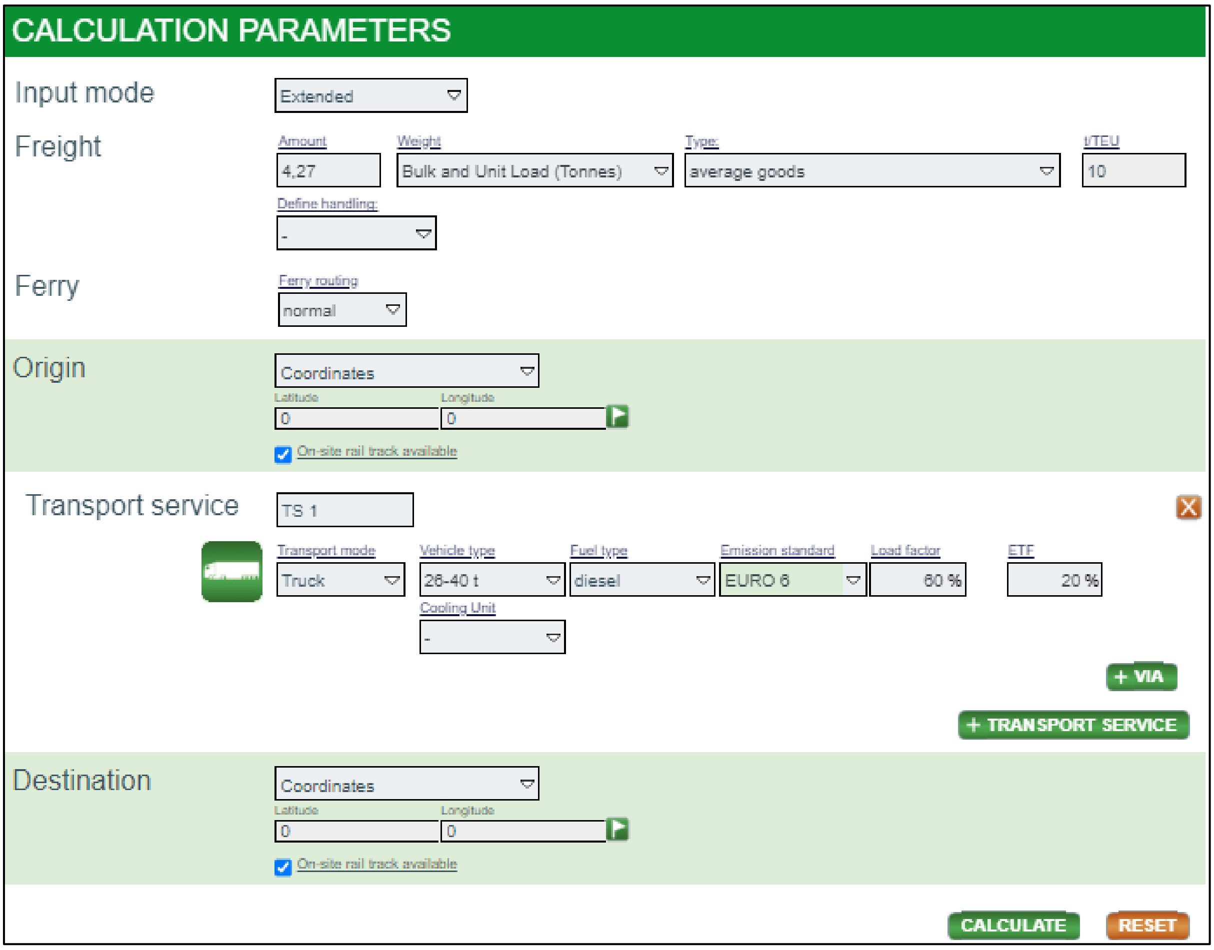
	TSTruck
Truck	1,886
Sum:	**1,886**

© EcoTransIT.org

Figure 8: EcoTransIT - Output data

Case 2: Extended version (ETW)

The extended version of EcoTransIT has more options for input, including type of goods, which again affect the t/TEU parameter connected to container-based weight parameter, load factor and empty trip factor (ETF) with default values for these. Another additional input is to define the handling of the goods when changing transport modes, which was left blank because the routes were limited to road. Ferries were set to normal because avoiding them would be infeasible for comparability to normal routing of goods between Norway and the destinations in Europe. Only truck transport was selected as transport mode, with default values for vehicle type 26-40t, diesel fuel, load factor 60% and empty trip factor 20%. Emission standard EURO 5 was default but changed to EURO 6. Further analysis of the selected choices will be presented later in this chapter. The output parameters were the same as in the standard version.



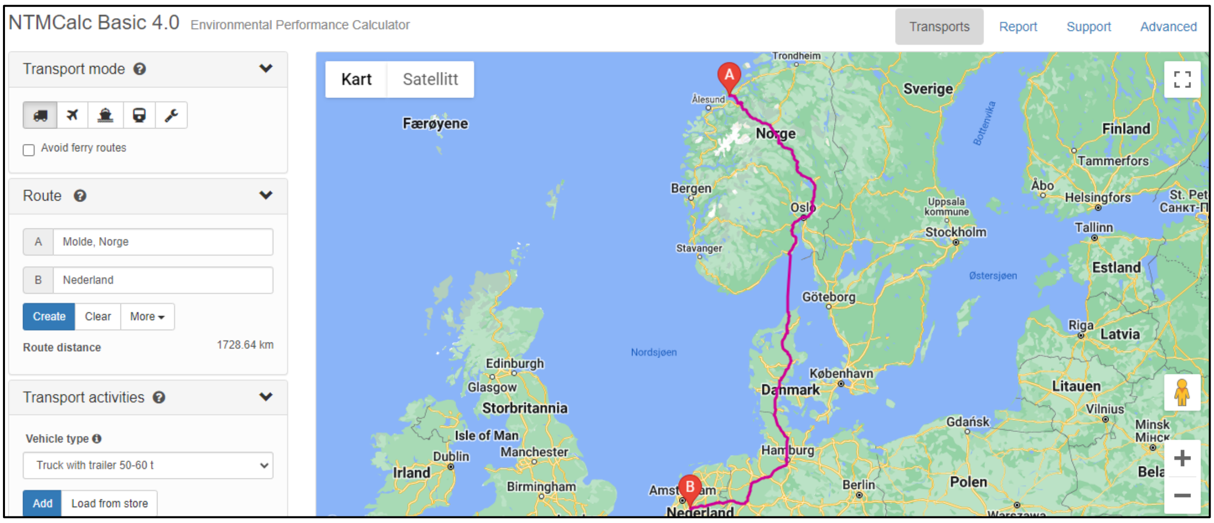
CALCULATION PARAMETERS

Input mode		Extended
Freight	Amount	4,27
	Weight	Bulk and Unit Load (Tonnes)
	Type:	average goods
	t/TEU	10
	Define handling:	-
Ferry	Ferry routing	normal
Origin		Coordinates
	Latitude	0
	Longitude	0
	☑ On-site rail track available	
Transport service		TS 1
	Transport mode	Truck
	Vehicle type	26-40 t
	Fuel type	diesel
	Emission standard	EURO 6
	Load factor	60 %
	ETF	20 %
	Cooling Unit	-
Destination		Coordinates
	Latitude	0
	Longitude	0
	☑ On-site rail track available	

Figure 9: EcoTransIT extended version - Input data

Case 3: Basic version (NTMCalc)

The NTM calculator provides less input compared to EcoTransIT, with choices of transport mode, avoiding ferries, routing, vehicle type and shipment weight. The two screenshots below show the options, with only the basic 4.0 version available as a free tool online. The basic version limits the route to origin and destination, where coordinates, addresses, and more can be inserted to create a route and then the tool illustrates it in the map on the left.



A Molde, Norge

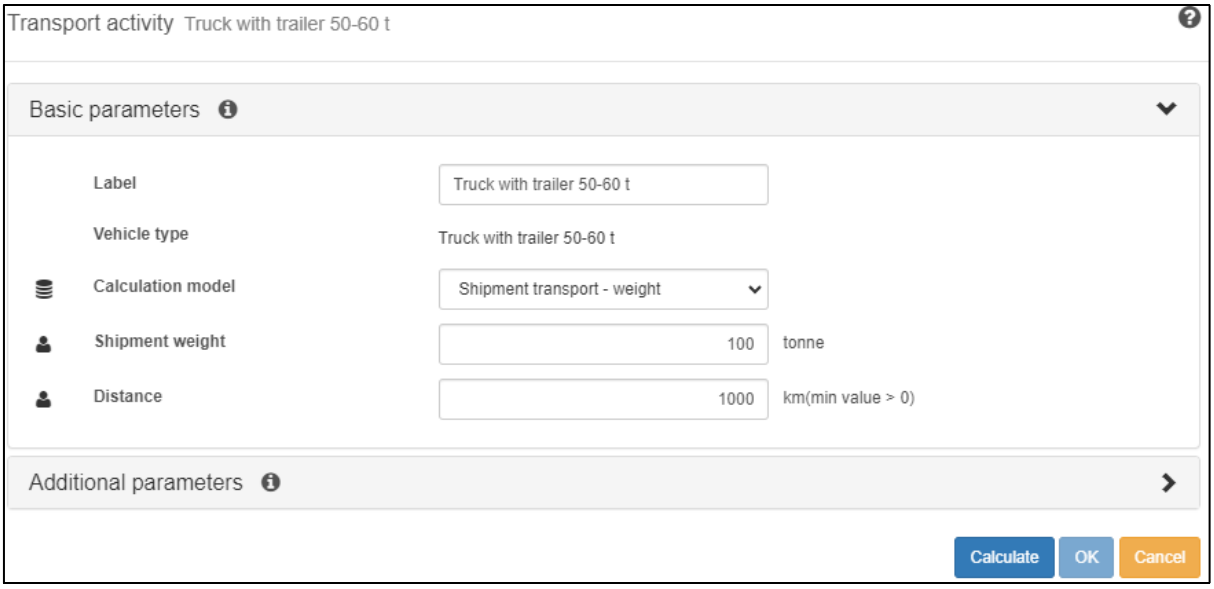
B Nederland

Route distance 1728.64 km

Vehicle type: Truck with trailer 50-60 t

Figure 10: NTMCalc Basic - Input

When adding the vehicle type, another window is displayed for the input of shipment weight in tonnes and distance in kilometres (km), which can be used as a substitute for the detailed routing inputs. The selected input parameters used in the calculations were truck as a transport mode, truck with trailer 50-60 tonnes, weight, and distance for a more precise and comparable outcomes. Further analysis of the selected choices will be presented later in this chapter.



Transport activity Truck with trailer 50-60 t

Label: Truck with trailer 50-60 t

Vehicle type: Truck with trailer 50-60 t

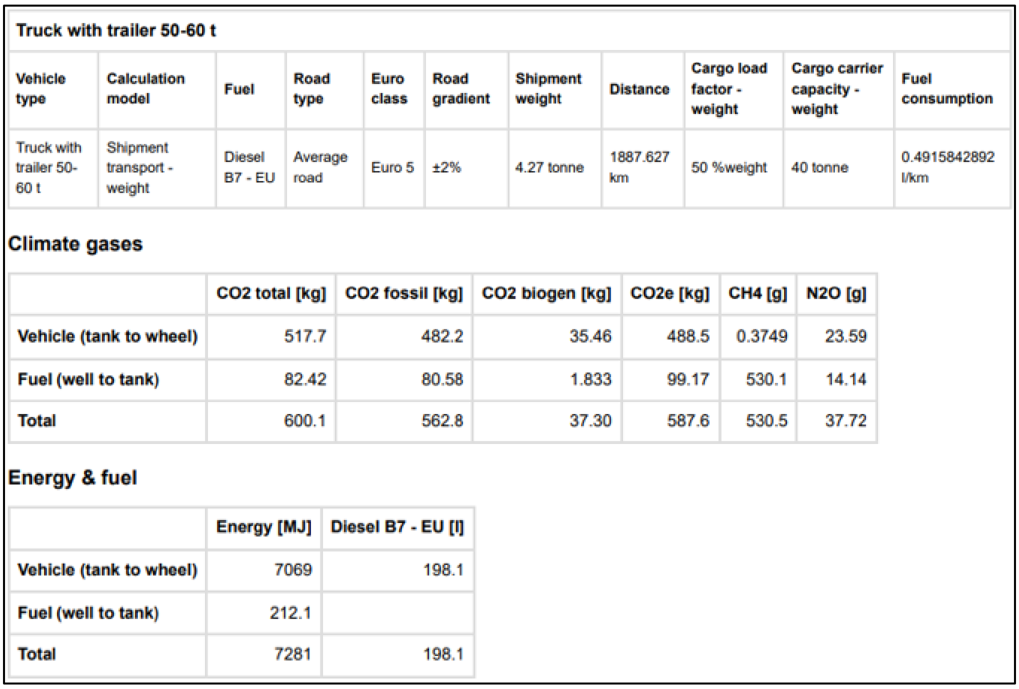
Calculation model: Shipment transport - weight

Shipment weight: 100 tonne

Distance: 1000 km(min value > 0)

Figure 11: NTMCalc Basic – Input

The output illustrated in the screenshot below included information about the default values the tool uses for calculating, such as road type, euro class, road gradient, cargo load factor in weight, and details related to the chosen vehicle type, that is fuel, cargo carrier capacity in weight, and fuel consumption litre per km. In addition, there are outputs for climate gasses for both TTW and WTW, for CO_2 (kg), CO_2 fossil (kg), CO_2 biogen (kg), CO_2e (kg), CH_4 (g), N_2O (g), Energy consumption (MJ), and diesel B7 – EU (L).



Truck with trailer 50-60 t

Vehicle type	Calculation model	Fuel	Road type	Euro class	Road gradient	Shipment weight	Distance	Cargo load factor - weight	Cargo carrier capacity - weight	Fuel consumption
Truck with trailer 50-60 t	Shipment transport - weight	Diesel B7 - EU	Average road	Euro 5	±2%	4.27 tonne	1887.627 km	50 %weight	40 tonne	0.4915842892 l/km

Climate gases

	CO2 total [kg]	CO2 fossil [kg]	CO2 biogen [kg]	CO2e [kg]	CH4 [g]	N2O [g]
Vehicle (tank to wheel)	517.7	482.2	35.46	488.5	0.3749	23.59
Fuel (well to tank)	82.42	80.58	1.833	99.17	530.1	14.14
Total	600.1	562.8	37.30	587.6	530.5	37.72

Energy & fuel

	Energy [MJ]	Diesel B7 - EU [l]
Vehicle (tank to wheel)	7069	198.1
Fuel (well to tank)	212.1	
Total	7281	198.1

Figure 12: NTMCalc Basic - Output

5.2 Selecting the routes

The selecting of routes as the basis for the inputs for the calculators were based on several criteria. It was important that the output from the deliveries in the data collection was comparable with the outputs of the calculators, which meant that any complexities for the routes was avoided. Glamox have outgoing shipments to several international countries, to both customers and distribution centres. They cooperate with several transportation companies, most notably Schenker for most of the heavy goods domestic and to European countries, DHL for express and some economy, and as of lately Kuehne + Nagel for some routes with heavy goods. Schenker has been the main transporter with multiple weekly shipments by trucks, however, some of these routes have now been taken over by Kuehne + Nagel. DHL is mainly used for limited weight express shipments to multiple separate customers, by either truck or flight. Consolidated shipments with multiple customers are much more complex to calculate correctly because of many factors regarding allocating the emissions for each customer on a shared vehicle. Therefore, the routes were selected according to the least complicated outcomes and involved choosing shipments to distribution centres in Europe, preferably with truck as the only transport mode. The chosen destinations were distribution centres in The Netherlands and England, with no further distribution to customers from the terminals in Europe. Routing from Glamox to Europe normally stops in Oslo at the transportation company's terminals for re-loading the goods to other trucks with same destinations and consolidating goods from Glamox's other factory at Kirkenær. Therefore, the deliveries to these countries, which is the data used for input in the calculators, were picked based on high volume and weight to ensure high load factor and avoid any re-loading or consolidation.

5.3 Limited quantitative data collection

The data was collected from Glamox and the three transportation companies DB Schenker, DHL, and Kuehne + Nagel. They all provided varying detailed emission data reports on inputs and outputs from emission calculation reports, however, due to the nature of the selected routes only the data from Schenker will be used when comparing the calculators. The express service of DHL is very often consolidated, and Kuehne + Nagel just began their transportations for Glamox this year and was therefore unable to produce enough historical data from their road transport, which also only contained emission estimates for CO_2e WTW. Furthermore, due to confidentiality and safety reasons stated by the transportation companies, all three companies were unable to disclose too specific details on their calculation methods, routes, and more. This led to a lot of details behind the data were left unanswered, and presumptions about the details had to be made during the execution of the cases.

5.4 The effect of the input data on the output

Prior to starting the calculations of the deliveries, multiple tests were executed to examine how the differences in the input parameters affected the output for all calculators. Starting with the routes and how they were calculated with the calculators.

5.4.1 Routes

Due to limited details behind the routes in the data collection, the first part in recreating the routes was to figure out the typical transport routing system in Europe. The TEN-T core network corridors provided by the Trans-European Transport Network, as illustrated below in a simplified combination of overlapping road, rail and inland water routes, showed the possible routes from Norway into Europe. These were from Oslo, through Sweden and Denmark, or from Oslo with boat to Denmark (not outlined in the figure). One important discovery was the route connecting Denmark with Germany with a ferry, as an alternative to continuing west in Denmark and then south, crossing the border to Germany by land.

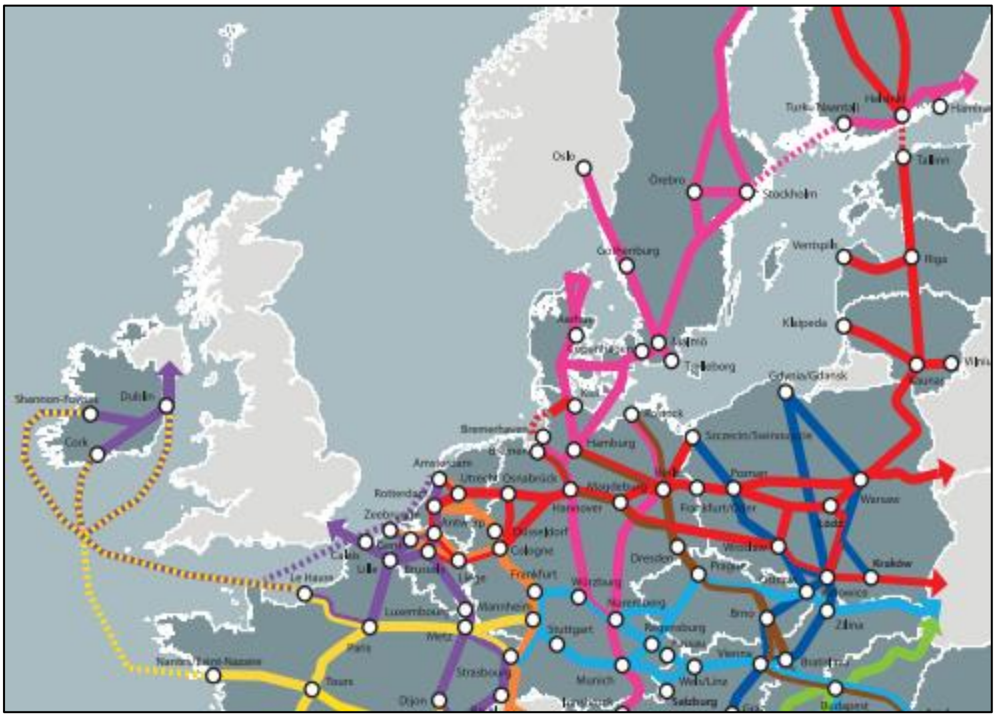


Figure 13: TEN-T Core Network Corridors (EU 2021)

Continuing with this knowledge, the possible routes to the destinations in The Netherlands and England were recreated using Google Maps and exact coordinates of the origin and destination. Google Maps presented two automatic route options from Molde to Europe, however, option one from Norway to Denmark by ferry was 73,84 km too short and option two through Sweden then Denmark was 43,16 km too long compared to the distance data from Schenker. On the other hand, the default routing of the EcoTransIT standard version, with no options for waypoints, produced a distance which deviated by 2,45 km from Schenker. The report from EcoTransIT with coordinates as input, as illustrated in the screenshot below, suggested that the route went from Molde in Norway down to Oslo, crossed into Sweden, entered Denmark with a ferry between Helsingborg in Sweden and Helsingör in Denmark, entered Germany with a ferry from Rødbyhavn in Denmark to Puttgarden in Germany, and then drove to the destination in The Netherlands. Google

Maps suggested entering Denmark from Sweden with the Öresund Bridge, however, recreating the ferry crossing from Helsingborg produced a route 0,16 km from Schenker.

Transport service Road

Distance [km]	Transport mode	Origin	Destination
1,000.86	Truck		56.044143 / 12.691174
5.00	Truck (Ferry)	56.044143 / 12.691174	56.033089 / 12.61581
200.62	Truck	56.033089 / 12.61581	54.654368 / 11.350885
18.68	Truck (Ferry)	54.654368 / 11.350885	54.502328 / 11.227825
661.22	Truck	54.502328 / 11.227825	

Summary: 1,886.39 km

Country specific distance [km]
Norway: 607.87
Sweden: 393.00
[dk - se]: 5.00
Denmark: 200.62
[de - dk]: 18.68
Germany: 437.69
Netherlands: 223.53

Figure 14: Route details from EcoTransIT standard

The following figure visualise the route options recreated in Google Maps, with the first being Norway to Denmark by ferry, second is border crossing from Sweden to Denmark with the Öresund Bridge, third is ferry from Helsingborg in Sweden to Helsingör in Denmark, and fourth is the route produced by EcoTransIT.

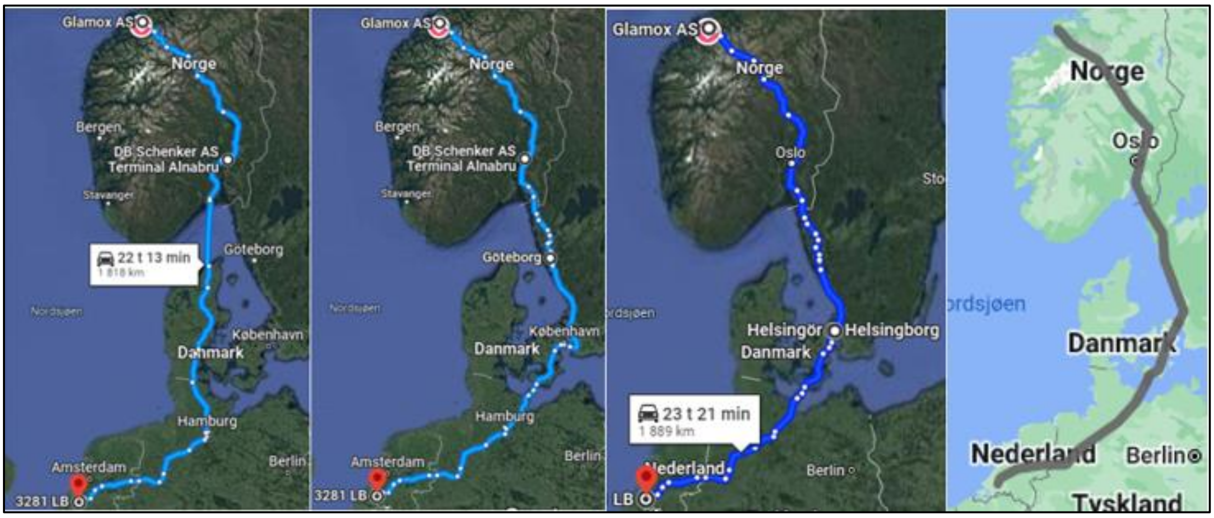
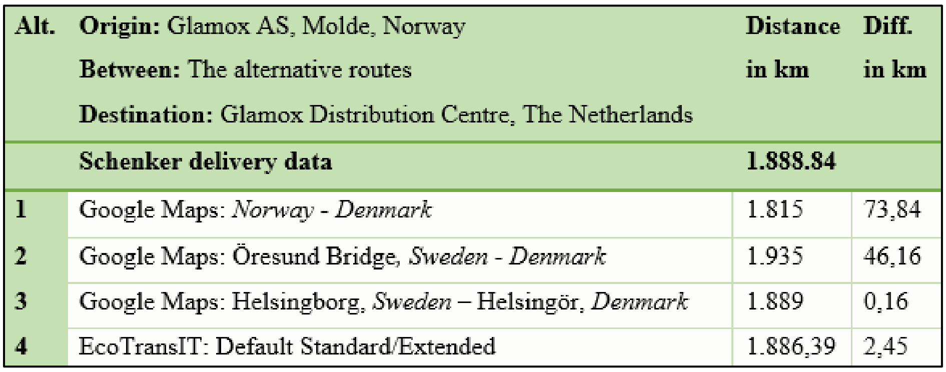


Figure 15: Four visualised route option from Molde to The Netherlands

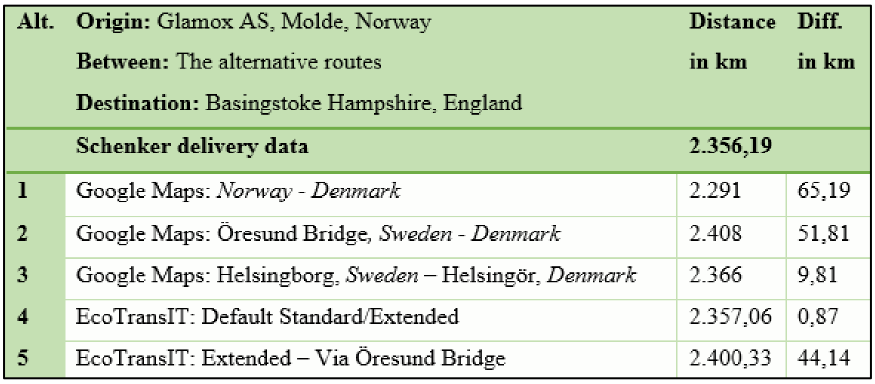
The table below presents the results of the four options with different stops in between the origin and destination compared to the data from Schenker.



Alt.	**Origin:** Glamox AS, Molde, Norway **Between:** The alternative routes **Destination:** Glamox Distribution Centre, The Netherlands	Distance in km	Diff. in km
	Schenker delivery data	**1.888.84**	
1	Google Maps: *Norway - Denmark*	1.815	73,84
2	Google Maps: Öresund Bridge, *Sweden - Denmark*	1.935	46,16
3	Google Maps: Helsingborg, *Sweden* – Helsingör, *Denmark*	1.889	0,16
4	EcoTransIT: Default Standard/Extended	1.886,39	2,45

Table 3: Route distances from Molde to The Netherlands

The same procedure of comparing results produced with Google Maps and EcoTransIT were conducted to determine the best route options for the deliveries from Molde to England. The routes created in Google Maps and produced by EcoTransIT displayed the same options as for the routes to The Netherlands, in addition to continuing through The Chunnel Tunnel to cross the border from France to England. The table below presents the results of the different route options, the distances, and the differences compared to Schenker. This also included an extra option of a waypoint to the Öresund Bridge using EcoTransIT extended version.



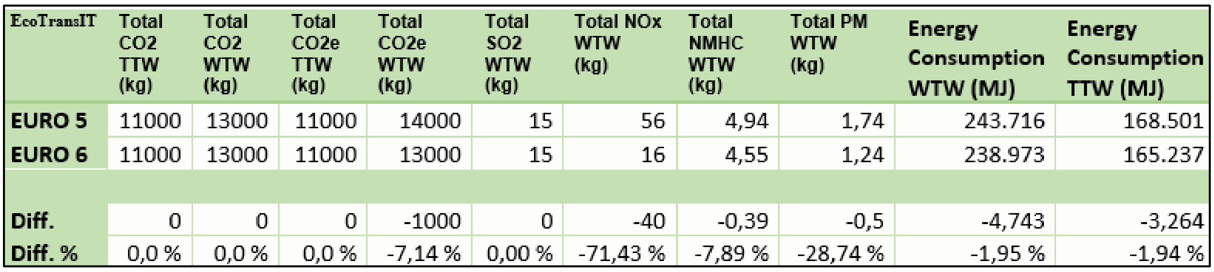
Alt.	**Origin:** Glamox AS, Molde, Norway **Between:** The alternative routes **Destination:** Basingstoke Hampshire, England	Distance in km	Diff. in km
	Schenker delivery data	**2.356,19**	
1	Google Maps: *Norway - Denmark*	2.291	65,19
2	Google Maps: Öresund Bridge, *Sweden - Denmark*	2.408	51,81
3	Google Maps: Helsingborg, *Sweden* – Helsingör, *Denmark*	2.366	9,81
4	EcoTransIT: Default Standard/Extended	2.357,06	0,87
5	EcoTransIT: Extended – Via Öresund Bridge	2.400,33	44,14

Table 4: Route distances from Molde to England

Following the results for routes to both The Netherlands and England, the default values for EcoTransIT presented the overall results with the least deviations compared to the delivery distance data from Schenker. This is as expected considering Schenker uses EcoTransIT for their emissions computations, however, if the numbers represent the reality, it was unexpected that the freight route included a ferry trip and not crossing the Öresund Bridge to avoid ferries. The EcoTransIT standard version did not have options for routing, however, the added route option to the Öresund bridge in the extended version did not present any closer results to Schenker. Additional information is that EcoTransIT calculates ferries as part of the road transport. This concluded that the default routing in combination with coordinates for a more precise result was used instead for the calculation of the deliveries. For NTMCalc, the distance from the deliveries by Schenker was used directly instead of recreating the routing. A test with data from the Google Maps routes was conducted using coordinates in the routing section from, and it produced the same results as just inserting the distance.

5.4.2 Emission standard

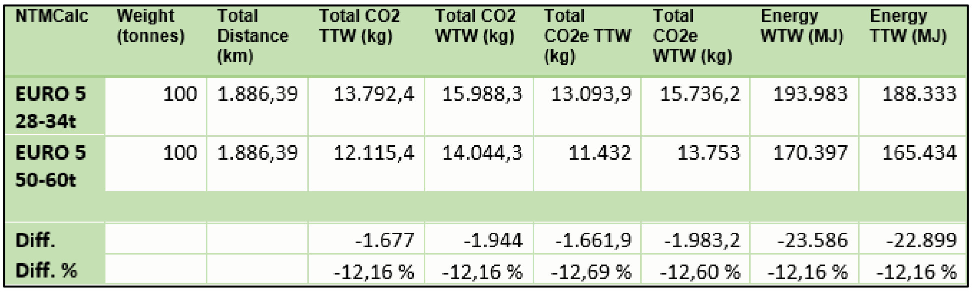
Both the standard version of EcoTransIT and basic version of NTMCalc uses emission standard classification EURO 5, which was introduced in 2014. The extended version of EcoTransIT gives the option of changing to EURO 6. A test to compare the differences between EURO 5 and EURO 6 was conducted using the distance of Molde to The Netherlands and as an example, with inputs of 100 tonnes, distance of 1.886,39 km, and outputs in kg and MJ. The produced results with EURO 5 and EURO 6 in the table below displayed no differences of the total CO_2 TTW and WTW, and CO_2e TTW. There were some minor differences for CO_2e WTW, NMHC, and energy consumption WTW and TTW. The most significant differences were for particulate matter (PM) and especially NOx, which is explained by a combination of advanced emission control technologies, lower NOx limits, optimised engine design, particulate matter control, and stringent testing procedures for EURO 6 vehicles.



EcoTransIT	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)	Energy Consumption WTW (MJ)	Energy Consumption TTW (MJ)
EURO 5	11000	13000	11000	14000	15	56	4,94	1,74	243.716	168.501
EURO 6	11000	13000	11000	13000	15	16	4,55	1,24	238.973	165.237
Diff.	0	0	0	-1000	0	-40	-0,39	-0,5	-4,743	-3,264
Diff. %	0,0 %	0,0 %	0,0 %	-7,14 %	0,00 %	-71,43 %	-7,89 %	-28,74 %	-1,95 %	-1,94 %

Table 5: EcoTransIT - Differences between EURO 5 and 6

The NTMCalc basic version uses EURO 5 by default, and the same input of destination and distance was used to display the differences between the options of 38-34 tonnes vehicles compared to 50-60 tonnes. The results displayed in the table below produced the same deviant, however, comparing the numbers from EURO 5 EcoTransIT and NTMCalc there is a significant difference all together. The results from NTMCalc with a 50-60t vehicle is closer to EcoTransIT, although EcoTransIT records lower emissions with up to 1.000-2.000 kg in differences except for the energy consumption WTW where NTMCalc have lower emissions. EURO 5 was chosen as an input parameter when calculating with the EcoTransIT extended version to mirror the real world, where most modern freight vehicles are using EURO 6.

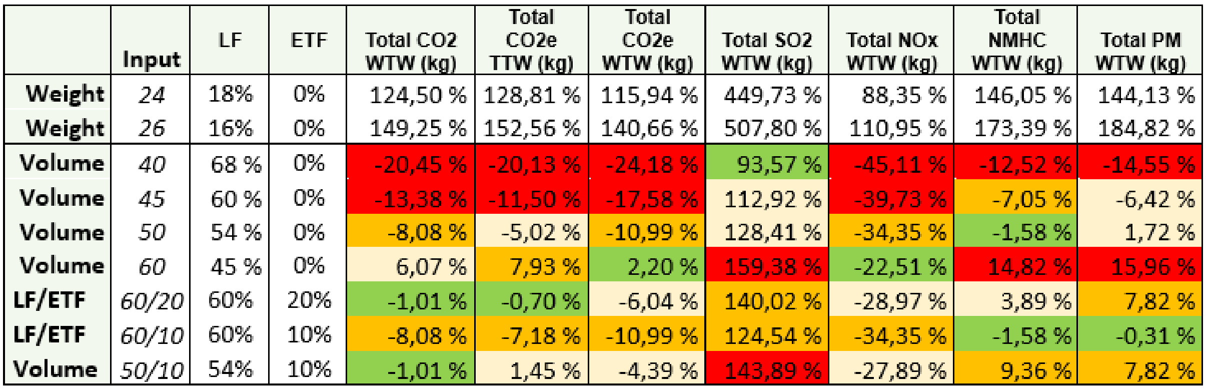


NTMCalc	Weight (tonnes)	Total Distance (km)	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Energy WTW (MJ)	Energy TTW (MJ)
EURO 5 28-34t	100	1.886,39	13.792,4	15.988,3	13.093,9	15.736,2	193.983	188.333
EURO 5 50-60t	100	1.886,39	12.115,4	14.044,3	11.432	13.753	170.397	165.434
Diff.			-1.677	-1.944	-1.661,9	-1.983,2	-23.586	-22.899
Diff. %			-12,16 %	-12,16 %	-12,69 %	-12,60 %	-12,16 %	-12,16 %

Table 6: NTMCalc - Differences between 28-34t and 50-60t vehicles

5.4.3 Load factor and empty trip factor

The load factor specifies the utilisation of the capacity of the transport vehicle, with 100% being the maximum, and the empty trip factor is the additional distance that the truck must travel when empty. The load factor (LF) and empty trip factor (ETF) have default values of 60% and 20% in the standard EcoTransIT version, and the NTMCalc basic has a default value for the cargo load factor which is 50% of the weight. The extended EcoTransIT version allow for different inputs for both LF and ETF, including options for types of heavy, average, and light goods which produces default values for t/TEU (container based), LF, and ETF. Several experiments were conducted using a delivery to The Netherland with Schenker as input and EURO 6 to find out which load factor was to be used for the calculations of the deliveries, and they were based on three approaches. First approach involved calculating the load factor by the weight of the goods, divided by the payload capacity of the diesel truck, which for an average truck was either 24 or 26 tonnes. The second approach was to calculate the load factor by the volume of the truck, which was unknown and therefore five options were tested. The last approach was to use the default values of 60% LF and 20% ETF and try with 10% ETF. It is not disclosed if the data from Schenker is calculated including ETF, and empty trips were not initially included as part of the plan when creating the cases. However, the differences in the table below between the volume example of 50% LF with 0% ETF and 50% LF with 10% ETF displays a significant reduce in CO_2, CO_2e and NOx emissions, but an increase in SO_2, NMHC and PM.



	Input	LF	ETF	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
Weight	*24*	18%	0%	124,50 %	128,81 %	115,94 %	449,73 %	88,35 %	146,05 %	144,13 %
Weight	*26*	16%	0%	149,25 %	152,56 %	140,66 %	507,80 %	110,95 %	173,39 %	184,82 %
Volume	*40*	68 %	0%	-20,45 %	-20,13 %	-24,18 %	93,57 %	-45,11 %	-12,52 %	-14,55 %
Volume	*45*	60 %	0%	-13,38 %	-11,50 %	-17,58 %	112,92 %	-39,73 %	-7,05 %	-6,42 %
Volume	*50*	54 %	0%	-8,08 %	-5,02 %	-10,99 %	128,41 %	-34,35 %	-1,58 %	1,72 %
Volume	*60*	45 %	0%	6,07 %	7,93 %	2,20 %	159,38 %	-22,51 %	14,82 %	15,96 %
LF/ETF	*60/20*	60%	20%	-1,01 %	-0,70 %	-6,04 %	140,02 %	-28,97 %	3,89 %	7,82 %
LF/ETF	*60/10*	60%	10%	-8,08 %	-7,18 %	-10,99 %	124,54 %	-34,35 %	-1,58 %	-0,31 %
Volume	*50/10*	54%	10%	-1,01 %	1,45 %	-4,39 %	143,89 %	-27,89 %	9,36 %	7,82 %

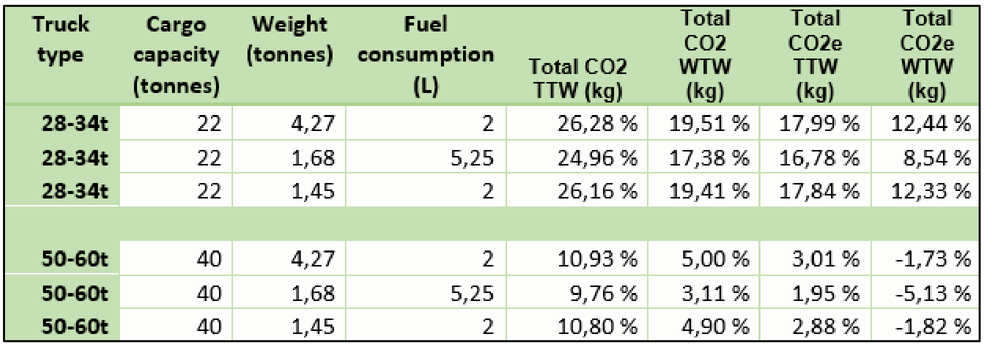
Table 7: Differences in load factor and empty trip factor for EcoTransIT

The results are presented in the table above as the difference in percentage compared to a delivery example to The Netherlands and have been highlighted according to which values are least and most deviant (green – light orange – orange – red). The load factors based on weight increased so significantly due to the low weight and subsequently low load factors that they are not relevant for further use, while the volume of 40 and 45 m^3 had overall increased values. The volumes of 50 and 60 m^3 were on average a closer match to the Schenker delivery, and volume of 50 m^3 with 10% ETF increased the differences even more. However, the default values of 60% LF and 20% ETF had the overall least average deviant values and further calculations with the extended EcoTransIT version will use this as input.

5.4.4 Type of vehicle

The EcoTransIT extended version gives the option to change the vehicle type from the default 26-40 tonnes type to multiple different vehicle types with other weight measurements. However, the default type is based on the average truck used for freight in Europe and was therefore selected for the calculations. Similar to EcoTransIT, NTMCalc offers choices for multiple vehicle types for freight transport, most notably truck with trailer 28-34 tonnes and 50-60 tonnes. The differences between these were presented when discussing the emission standards, however, another test is conducted using three deliveries to England with different gross weight in tonnes and same distance of 2.356,19 km. The table below displays the significant differences of using a 28-34t truck and 50-60t truck, where there is an overall decrease of the emissions when using a 50-60t truck.

Although the output among the three deliveries displays similar results, the output for delivery of 1,68 tonnes is a little bit lower than the other two. The Schenker data for this delivery included a detailed number for the fuel consumption, in contrast to many of the other deliveries which had a default value of 2 Litres. The specific details for fuel consumption might be a contributing factor for how the Schenker data was calculated. Based on the results in the table below, further calculations using the NTMCalc basic was conducted with the truck type of 50-60t.



Truck type	Cargo capacity (tonnes)	Weight (tonnes)	Fuel consumption (L)	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)
28-34t	22	4,27	2	26,28 %	19,51 %	17,99 %	12,44 %
28-34t	22	1,68	5,25	24,96 %	17,38 %	16,78 %	8,54 %
28-34t	22	1,45	2	26,16 %	19,41 %	17,84 %	12,33 %
50-60t	40	4,27	2	10,93 %	5,00 %	3,01 %	-1,73 %
50-60t	40	1,68	5,25	9,76 %	3,11 %	1,95 %	-5,13 %
50-60t	40	1,45	2	10,80 %	4,90 %	2,88 %	-1,82 %

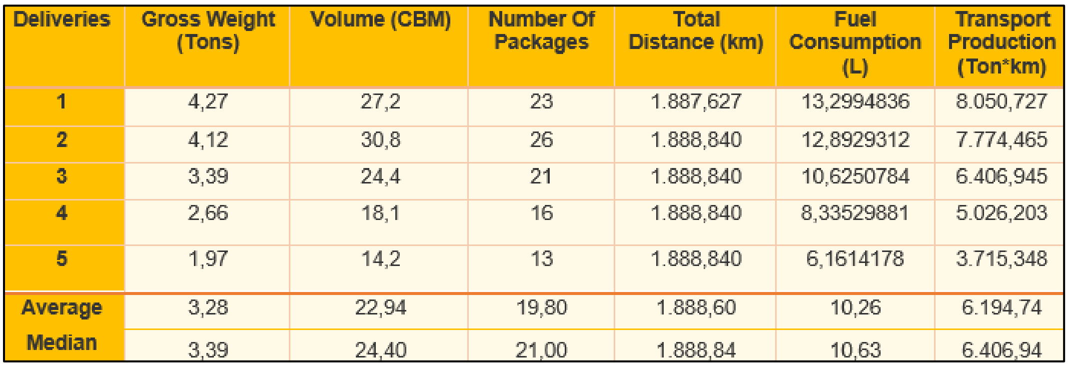
Table 8: NTMCalc output from different vehicle types

5.5 Results, analysis and findings of the calculations

The input from the data collection from Schenker is presented in the following four tables for The Netherlands and England, where five deliveries for The Netherlands and six deliveries for England has been selected according to high and medium volumes and weight, with additional calculated values for the average and median. An average volume of maximum 40 m^3 was set due to the uncertainty of the unknown truck volumes, and the deliveries are displayed corresponding to ascending gross weight values. All tables for the calculations using EcoTransIT and NTMCalc has been divided by colour to distinguish between the countries, where ***orange*** represents The Netherlands, and ***blue*** represents England.

Input - The Netherlands

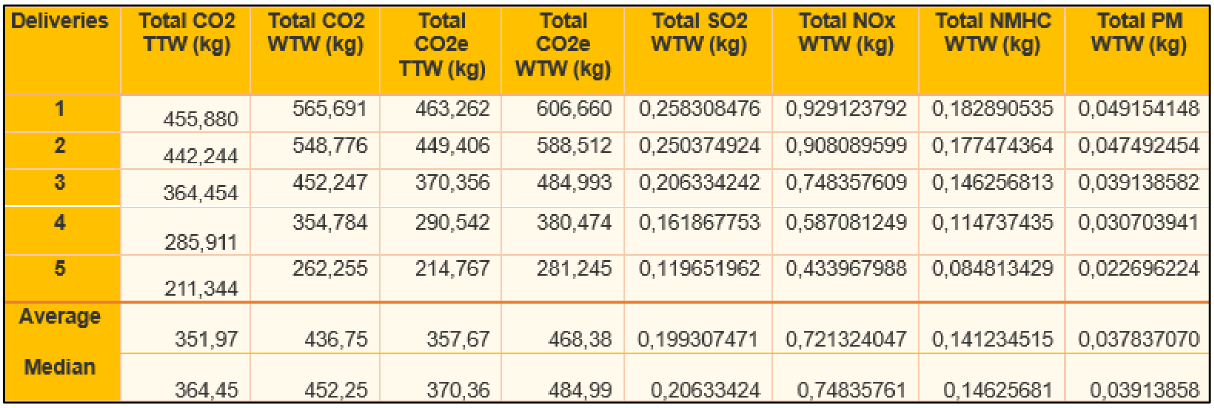
In the following table, the distance is constant for all deliveries with minor deviations for delivery 1. All deliveries have varying fuel consumption and transport production, which is the calculated tonne-kilometre.



Deliveries	Gross Weight (Tons)	Volume (CBM)	Number Of Packages	Total Distance (km)	Fuel Consumption (L)	Transport Production (Ton*km)
1	4,27	27,2	23	1.887,627	13,2994836	8.050,727
2	4,12	30,8	26	1.888,840	12,8929312	7.774,465
3	3,39	24,4	21	1.888,840	10,6250784	6.406,945
4	2,66	18,1	16	1.888,840	8,33529881	5.026,203
5	1,97	14,2	13	1.888,840	6,1614178	3.715,348
Average	3,28	22,94	19,80	1.888,60	10,26	6.194,74
Median	3,39	24,40	21,00	1.888,84	10,63	6.406,94

Table 9: Schenker deliveries - The Netherlands

Noticeable trends include that there is a connection between the input of weight and output of emissions, wherein example delivery 1 has overall higher emissions than delivery 5. This indicates that the emissions are calculated based on the tonne-km, which is the weight of the goods per kilometre, rather than the share of utilised and empty capacity, and is explained by how the weight of a truck load exhaust more emissions.

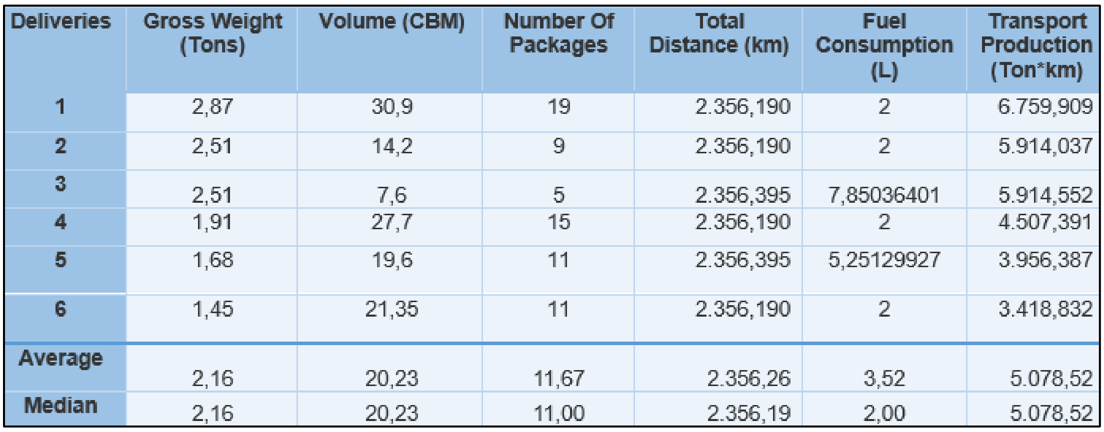


Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	455,880	565,691	463,262	606,660	0,258308476	0,929123792	0,182890535	0,049154148
2	442,244	548,776	449,406	588,512	0,250374924	0,908089599	0,177474364	0,047492454
3	364,454	452,247	370,356	484,993	0,206334242	0,748357609	0,146256813	0,039138582
4	285,911	354,784	290,542	380,474	0,161867753	0,587081249	0,114737435	0,030703941
5	211,344	262,255	214,767	281,245	0,119651962	0,433967988	0,084813429	0,022696224
Average	351,97	436,75	357,67	468,38	0,199307471	0,721324047	0,141234515	0,037837070
Median	364,45	452,25	370,36	484,99	0,20633424	0,74835761	0,14625681	0,03913858

Table 10: Schenker deliveries - The Netherlands

Input - England

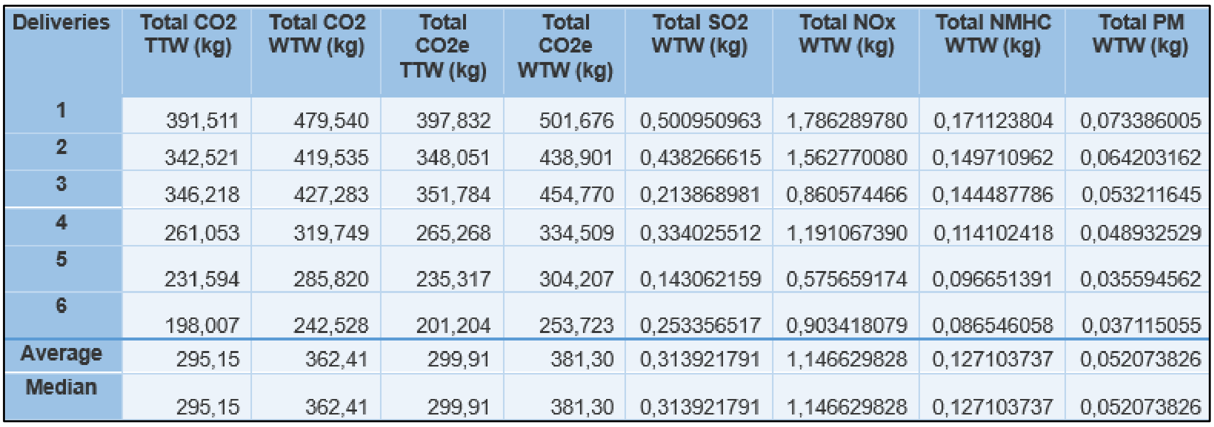
The following tables presents the selected deliveries with Schenker to England. There are notable differences in the fuel consumption numbers of delivery 3 and 5, which are more precise than the rest that appear to be default values.



Deliveries	Gross Weight (Tons)	Volume (CBM)	Number Of Packages	Total Distance (km)	Fuel Consumption (L)	Transport Production (Ton*km)
1	2,87	30,9	19	2.356,190	2	6.759,909
2	2,51	14,2	9	2.356,190	2	5.914,037
3	2,51	7,6	5	2.356,395	7,85036401	5.914,552
4	1,91	27,7	15	2.356,190	2	4.507,391
5	1,68	19,6	11	2.356,395	5,25129927	3.956,387
6	1,45	21,35	11	2.356,190	2	3.418,832
Average	2,16	20,23	11,67	2.356,26	3,52	5.078,52
Median	2,16	20,23	11,00	2.356,19	2,00	5.078,52

Table 11: Schenker deliveries – England

Almost all deliveries follow the ascending values according to the weight, however, delivery 3 and 5 have the lowest emissions for the total of NOx, NMHC, and PM. Taking into consideration of the precise fuel consumption values for these two deliveries versus the default values of the other deliveries, this indicates presumptions of varying degree of details for the calculations. This is especially evident considering delivery 2 and 3 have the same gross weight of 2,51 tonnes but have different volume and fuel consumption.

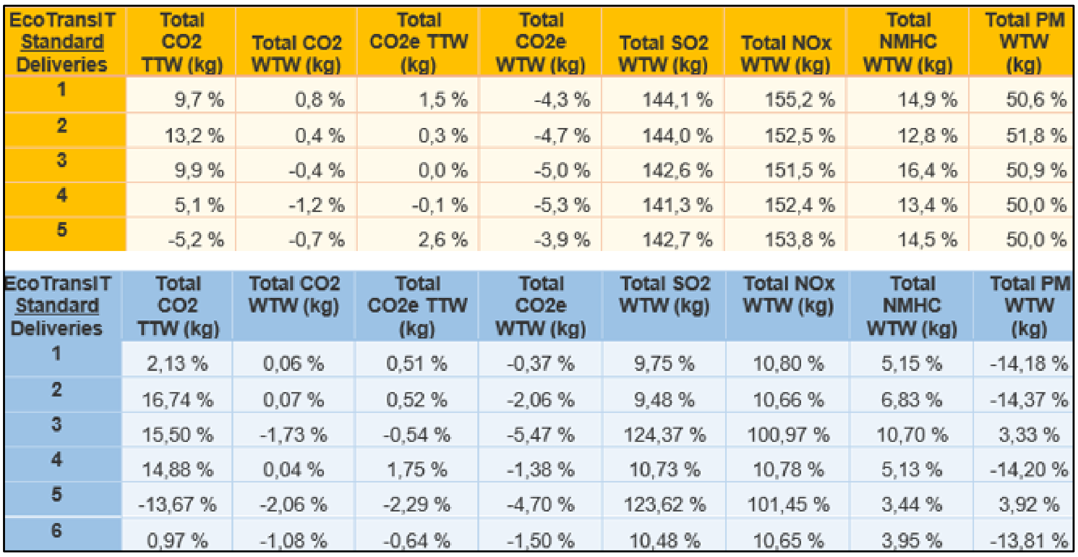


Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	391,511	479,540	397,832	501,676	0,500950963	1,786289780	0,171123804	0,073386005
2	342,521	419,535	348,051	438,901	0,438266615	1,562770080	0,149710962	0,064203162
3	346,218	427,283	351,784	454,770	0,213868981	0,860574466	0,144487786	0,053211645
4	261,053	319,749	265,268	334,509	0,334025512	1,191067390	0,114102418	0,048932529
5	231,594	285,820	235,317	304,207	0,143062159	0,575659174	0,096651391	0,035594562
6	198,007	242,528	201,204	253,723	0,253356517	0,903418079	0,086546058	0,037115055
Average	295,15	362,41	299,91	381,30	0,313921791	1,146629828	0,127103737	0,052073826
Median	295,15	362,41	299,91	381,30	0,313921791	1,146629828	0,127103737	0,052073826

Table 12: Schenker deliveries - England

5.5.1 Case 1: EcoTransIT standard

The following table displays the difference in percentage between the output for the deliveries with Schenker and the output using the standard version of EcoTransIT, for both The Netherlands and England. Considering the differences in the distance input, the results from both Schenker and EcoTransIT was first divided by tonne-km to create an equal and comparable baseline. The overall differences in increasing and decreasing CO_2 TTW and WTW, CO_2e TTW and WTW, and NMHC for The Netherlands are small, however, there is a significant increase from the Schenker data to the EcoTransIT results for SO_2, NOx, and PM. The reason for this can be the use of the emission standard EURO 5. Similar variations are present for deliveries 2 and 5 to England; nonetheless, deliveries 1, 2, 4, and 6 do not exhibit the same notably elevated differences for these emissions.



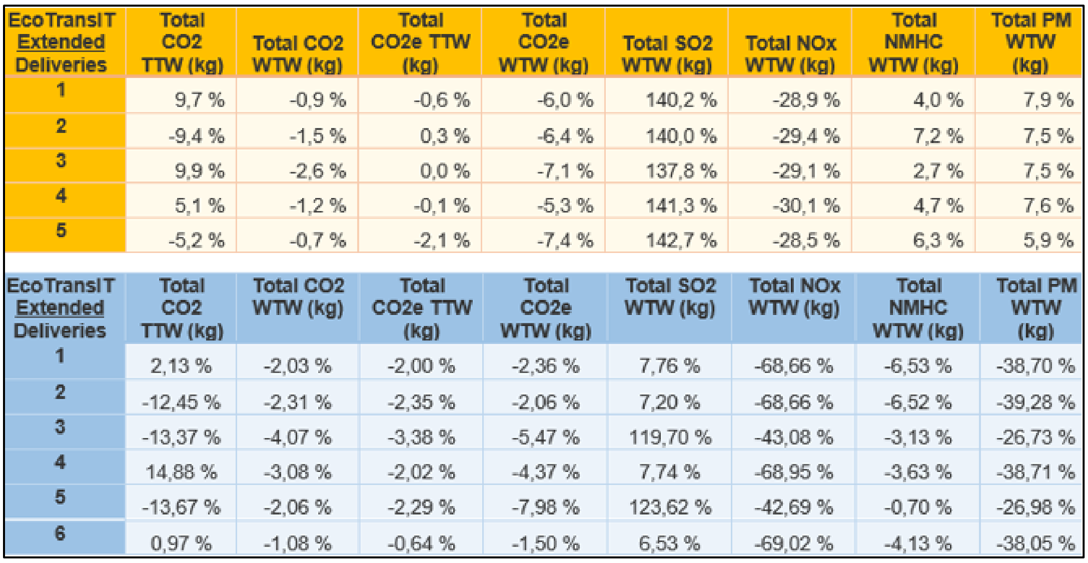
EcoTransIT Standard Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	9,7 %	0,8 %	1,5 %	-4,3 %	144,1 %	155,2 %	14,9 %	50,6 %
2	13,2 %	0,4 %	0,3 %	-4,7 %	144,0 %	152,5 %	12,8 %	51,8 %
3	9,9 %	-0,4 %	0,0 %	-5,0 %	142,6 %	151,5 %	16,4 %	50,9 %
4	5,1 %	-1,2 %	-0,1 %	-5,3 %	141,3 %	152,4 %	13,4 %	50,0 %
5	-5,2 %	-0,7 %	2,6 %	-3,9 %	142,7 %	153,8 %	14,5 %	50,0 %

EcoTransIT Standard Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	2,13 %	0,06 %	0,51 %	-0,37 %	9,75 %	10,80 %	5,15 %	-14,18 %
2	16,74 %	0,07 %	0,52 %	-2,06 %	9,48 %	10,66 %	6,83 %	-14,37 %
3	15,50 %	-1,73 %	-0,54 %	-5,47 %	124,37 %	100,97 %	10,70 %	3,33 %
4	14,88 %	0,04 %	1,75 %	-1,38 %	10,73 %	10,78 %	5,13 %	-14,20 %
5	-13,67 %	-2,06 %	-2,29 %	-4,70 %	123,62 %	101,45 %	3,44 %	3,92 %
6	0,97 %	-1,08 %	-0,64 %	-1,50 %	10,48 %	10,65 %	3,95 %	-13,81 %

Table 13: Differences between EcoTransIT standard and Schenker for The Netherlands and England

5.5.2 Case 2: EcoTransIT extended

The following table displays the difference in percentage between the output for the deliveries with Schenker and the output using the standard version of EcoTransIT, for both The Netherlands and England. The initial results were divided by tonne-km for a comparable baseline. The overall differences in increasing and decreasing CO_2 TTW and WTW, CO_2e TTW and WTW, NMHC, and PM for The Netherlands are small, with significantly increased values for SO_2 and NOx. Similar variations are present for the deliveries to England; however, PM have increased significantly, and deliveries 1, 2, 4, and 6 do not exhibit the same notably elevated differences for SO_2 as deliveries 3 and 5. In the extended version of EcoTransIT emission standard EURO 6 was used, which can explain the decrease and increase in some of the emissions.



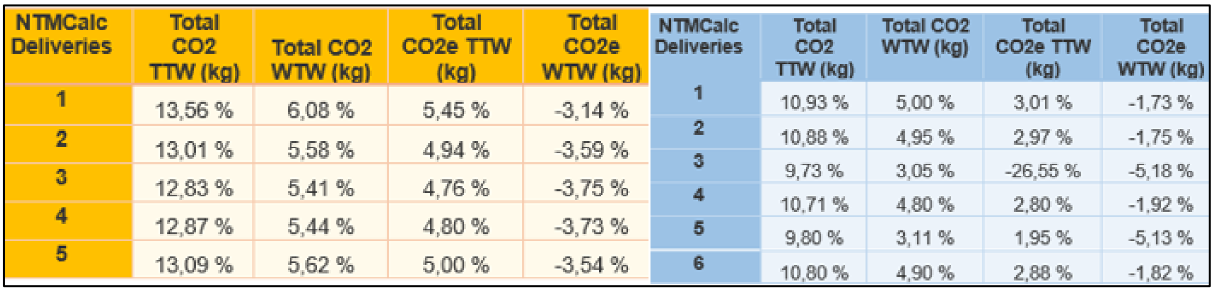
EcoTransIT Extended Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	9,7 %	-0,9 %	-0,6 %	-6,0 %	140,2 %	-28,9 %	4,0 %	7,9 %
2	-9,4 %	-1,5 %	0,3 %	-6,4 %	140,0 %	-29,4 %	7,2 %	7,5 %
3	9,9 %	-2,6 %	0,0 %	-7,1 %	137,8 %	-29,1 %	2,7 %	7,5 %
4	5,1 %	-1,2 %	-0,1 %	-5,3 %	141,3 %	-30,1 %	4,7 %	7,6 %
5	-5,2 %	-0,7 %	-2,1 %	-7,4 %	142,7 %	-28,5 %	6,3 %	5,9 %

EcoTransIT Extended Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	2,13 %	-2,03 %	-2,00 %	-2,36 %	7,76 %	-68,66 %	-6,53 %	-38,70 %
2	-12,45 %	-2,31 %	-2,35 %	-2,06 %	7,20 %	-68,66 %	-6,52 %	-39,28 %
3	-13,37 %	-4,07 %	-3,38 %	-5,47 %	119,70 %	-43,08 %	-3,13 %	-26,73 %
4	14,88 %	-3,08 %	-2,02 %	-4,37 %	7,74 %	-68,95 %	-3,63 %	-38,71 %
5	-13,67 %	-2,06 %	-2,29 %	-7,98 %	123,62 %	-42,69 %	-0,70 %	-26,98 %
6	0,97 %	-1,08 %	-0,64 %	-1,50 %	6,53 %	-69,02 %	-4,13 %	-38,05 %

Table 14: Differences between EcoTransIT extended and Schenker for The Netherlands and England

5.5.3 Case 3: NTMCalc

The following table displays the difference in percentage between the output for the deliveries with Schenker and the output using the basic version of NTMCalc, for both The Netherlands and England. The input for distance used when calculating with NTMCalc was identical to the distance sourced from the Schenker, and it was therefore not necessary to divide the results by tonne-km to create a comparable baseline. The overall differences display an increasing CO_2 TTW and WTW, and CO_2e TTW, and a decreasing CO_2e WTW for both The Netherland and England. However, CO_2e TTW for delivery 3 to England display a significant deviation compared to the resto of the values in the column.



NTMCalc Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)
1	13,56 %	6,08 %	5,45 %	-3,14 %
2	13,01 %	5,58 %	4,94 %	-3,59 %
3	12,83 %	5,41 %	4,76 %	-3,75 %
4	12,87 %	5,44 %	4,80 %	-3,73 %
5	13,09 %	5,62 %	5,00 %	-3,54 %

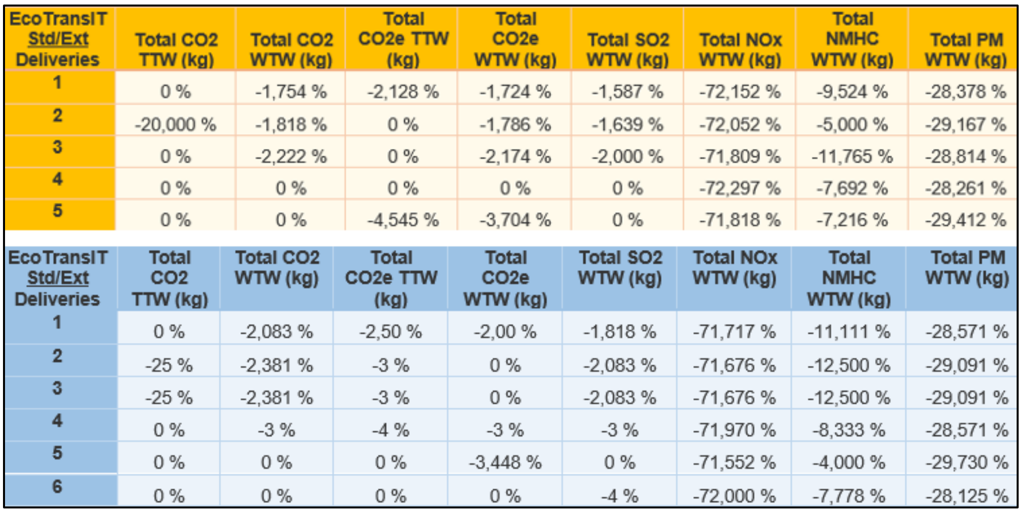
NTMCalc Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)
1	10,93 %	5,00 %	3,01 %	-1,73 %
2	10,88 %	4,95 %	2,97 %	-1,75 %
3	9,73 %	3,05 %	-26,55 %	-5,18 %
4	10,71 %	4,80 %	2,80 %	-1,92 %
5	9,80 %	3,11 %	1,95 %	-5,13 %
6	10,80 %	4,90 %	2,88 %	-1,82 %

Table 15: Differences between NTMCalc and Schenker for The Netherlands and England

5.5.4 Comparing the calculators

This subchapter compares and explores the differences between the calculators. The first table display the differences between the results from standard and extended version of

EcoTransIT, with results for The Netherland and England. The differences are based on actual output and not divided by tonne-km because both versions have the same input of weight and distance. The only difference is that the standard version was calculated with default emission standard EURO 5, and the extended was calculated with EURO 6. The use of different standard emissions is evident with an overall significant decrease in both NOx and PM, with smaller decrease in NMHC, for both countries. The reason for this has to do with the enhancements of various measures to reduce the emission in EURO 6 vehicles.

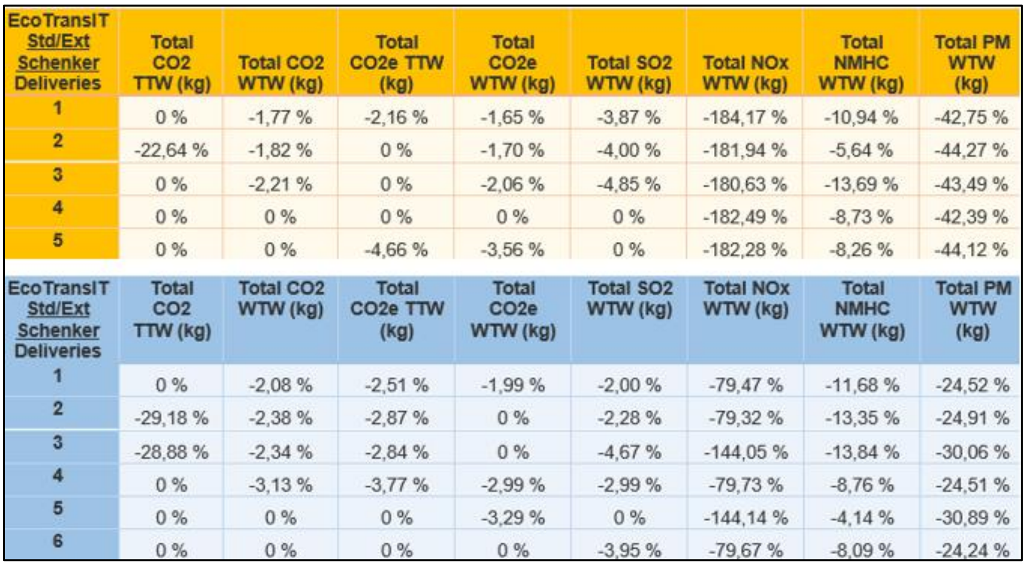


EcoTransIT Std/Ext Deliveries	**Total CO2 TTW (kg)**	**Total CO2 WTW (kg)**	**Total CO2e TTW (kg)**	**Total CO2e WTW (kg)**	**Total SO2 WTW (kg)**	**Total NOx WTW (kg)**	**Total NMHC WTW (kg)**	**Total PM WTW (kg)**
1	0 %	-1,754 %	-2,128 %	-1,724 %	-1,587 %	-72,152 %	-9,524 %	-28,378 %
2	-20,000 %	-1,818 %	0 %	-1,786 %	-1,639 %	-72,052 %	-5,000 %	-29,167 %
3	0 %	-2,222 %	0 %	-2,174 %	-2,000 %	-71,809 %	-11,765 %	-28,814 %
4	0 %	0 %	0 %	0 %	0 %	-72,297 %	-7,692 %	-28,261 %
5	0 %	0 %	-4,545 %	-3,704 %	0 %	-71,818 %	-7,216 %	-29,412 %

EcoTransIT Std/Ext Deliveries	**Total CO2 TTW (kg)**	**Total CO2 WTW (kg)**	**Total CO2e TTW (kg)**	**Total CO2e WTW (kg)**	**Total SO2 WTW (kg)**	**Total NOx WTW (kg)**	**Total NMHC WTW (kg)**	**Total PM WTW (kg)**
1	0 %	-2,083 %	-2,50 %	-2,00 %	-1,818 %	-71,717 %	-11,111 %	-28,571 %
2	-25 %	-2,381 %	-3 %	0 %	-2,083 %	-71,676 %	-12,500 %	-29,091 %
3	-25 %	-2,381 %	-3 %	0 %	-2,083 %	-71,676 %	-12,500 %	-29,091 %
4	0 %	-3 %	-4 %	-3 %	-3 %	-71,970 %	-8,333 %	-28,571 %
5	0 %	0 %	0 %	-3,448 %	0 %	-71,552 %	-4,000 %	-29,730 %
6	0 %	0 %	0 %	0 %	-4 %	-72,000 %	-7,778 %	-28,125 %

Table 16: Differences between the standard and extended version of EcoTransIT for The Netherland and England

The next table compares the differences in percentage between the results from each of the standard and extended versions of EcoTransIT with Schenker separately, for both The Netherlands and England. The overall differences are a small decrease in CO_2 TTW and WTW, CO_2e TTW and WTW, SO_2, and NMHC for both The Netherlands and England. Nonetheless, there is a significantly higher decrease in NOx and PM, which is due to the changed emission standard.

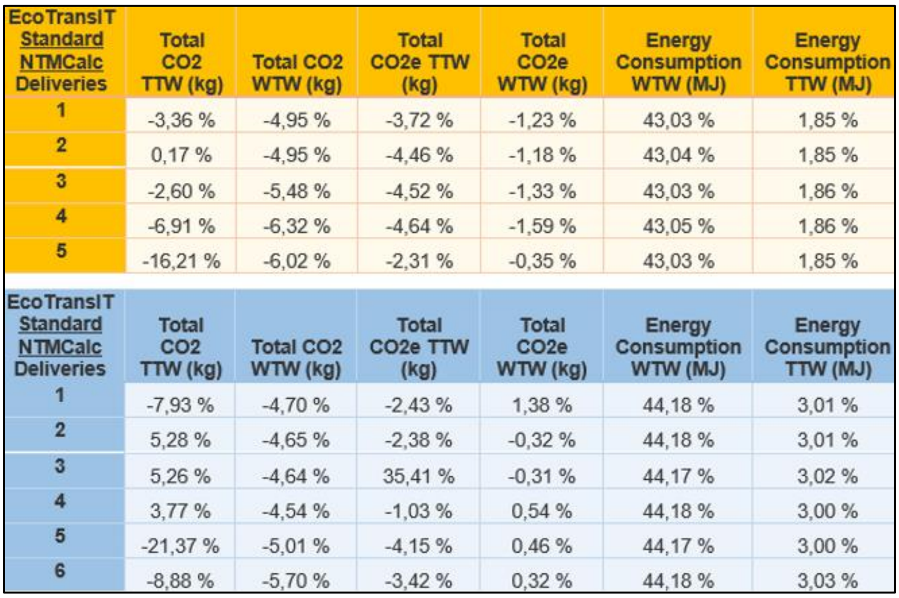


EcoTransIT Std/Ext Schenker Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	0 %	-1,77 %	-2,16 %	-1,65 %	-3,87 %	-184,17 %	-10,94 %	-42,75 %
2	-22,64 %	-1,82 %	0 %	-1,70 %	-4,00 %	-181,94 %	-5,64 %	-44,27 %
3	0 %	-2,21 %	0 %	-2,06 %	-4,85 %	-180,63 %	-13,69 %	-43,49 %
4	0 %	0 %	0 %	0 %	0 %	-182,49 %	-8,73 %	-42,39 %
5	0 %	0 %	-4,66 %	-3,56 %	0 %	-182,28 %	-8,26 %	-44,12 %

EcoTransIT Std/Ext Schenker Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	0 %	-2,08 %	-2,51 %	-1,99 %	-2,00 %	-79,47 %	-11,68 %	-24,52 %
2	-29,18 %	-2,38 %	-2,87 %	0 %	-2,28 %	-79,32 %	-13,35 %	-24,91 %
3	-28,88 %	-2,34 %	-2,84 %	0 %	-4,67 %	-144,05 %	-13,84 %	-30,06 %
4	0 %	-3,13 %	-3,77 %	-2,99 %	-2,99 %	-79,73 %	-8,76 %	-24,51 %
5	0 %	0 %	0 %	-3,29 %	0 %	-144,14 %	-4,14 %	-30,89 %
6	0 %	0 %	0 %	0 %	-3,95 %	-79,67 %	-8,09 %	-24,24 %

Table 17: Differences between the standard and extended version of EcoTransIT

The following table presents the differences between the NTMCalc and standard versions of EcoTransIT for The Netherlands and England. The extended was not included in this part because both NTMCalc use EURO 5 while the extended use EURO 6, and thus, the baseline is not comparable. Considering the differences in the distance input, both results were first divided by tonne-km to create an equal and comparable baseline. The is an overall small decrease and decrease for CO_2 TTW and WTW, CO_2e TTW and WTW, and Energy consumption TTW for both The Netherlands and England. Nonetheless, there is a significant increase in energy consumption WTW, indicating notable disparities in the calculations leading to these figures.



EcoTransIT Standard NTMCalc Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Energy Consumption WTW (MJ)	Energy Consumption TTW (MJ)
1	-3,36 %	-4,95 %	-3,72 %	-1,23 %	43,03 %	1,85 %
2	0,17 %	-4,95 %	-4,46 %	-1,18 %	43,04 %	1,85 %
3	-2,60 %	-5,48 %	-4,52 %	-1,33 %	43,03 %	1,86 %
4	-6,91 %	-6,32 %	-4,64 %	-1,59 %	43,05 %	1,86 %
5	-16,21 %	-6,02 %	-2,31 %	-0,35 %	43,03 %	1,85 %

EcoTransIT Standard NTMCalc Deliveries	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Energy Consumption WTW (MJ)	Energy Consumption TTW (MJ)
1	-7,93 %	-4,70 %	-2,43 %	1,38 %	44,18 %	3,01 %
2	5,28 %	-4,65 %	-2,38 %	-0,32 %	44,18 %	3,01 %
3	5,26 %	-4,64 %	35,41 %	-0,31 %	44,17 %	3,02 %
4	3,77 %	-4,54 %	-1,03 %	0,54 %	44,18 %	3,00 %
5	-21,37 %	-5,01 %	-4,15 %	0,46 %	44,17 %	3,00 %
6	-8,88 %	-5,70 %	-3,42 %	0,32 %	44,18 %	3,03 %

Table 18: The differences between NTMCalc Basic and EcoTransIT Standard

5.6 Findings and analysis of the qualitative data collection

A qualitative data collection with follow-up questions and interviews with the transportation companies was conducted to supplement the quantitative data. The qualitative approach had the intent to collect the missing information behind the quantitative numbers, however, different policies among the transportation companies prevented them to a variable degree of disclosing all asked details behind the operations. The following segments presents the collected answers for the follow-up questionnaire and interviews.

The first set of questions revolves around understanding the internal processes and motivations of why the transportation companies has decided to measure its emissions, the rationale for internal versus collaborative or outsourced computations of emissions, changes in customer demand for emissions information the last years, and lastly, what information the companies require from their customers for their emissions reports.

The consensus for all the transportation companies was that the motivation behind measuring their emissions followed different emissions goals from both internal and international policies of reducing their carbon footprints. Schenker is seeking to reduce their CO_2 emissions by 50% the next years by shifting towards more vehicles running on biogas and electricity, with the goal of the ordinary traffic and distribution being climate neutral by 2027. DHL is following their GoGreen program of commitment to environmental sustainability, reducing the carbon footprint of the operations and services, and have stated in their emissions reports that they work towards the global net zero emissions by 2050. Kuehne + Nagel opt for carbon neutral transportation by 2030, and while they offer freight options of biofuels and electricity, their electric fleet is limited, biofuels are expensive, and the willingness among customers to pay for these alternatives is low. The recent years interests and awareness of emissions reporting for the supply chain in general have increased the demand among the customers of the transportation companies asking for documentation, including Glamox AS. Kuehne + Nagel reports a significant increase among their customers just between the years 2022 to 2023.

The companies collaborate on different levels with an external outsourced emissions calculation company to calculate the emissions from their transportation, however, they also invest in the development of their own models for calculating and digital solutions for their customers. The reasons for this are related to access to direct resources, precision of allocating emissions per transport mode, and different average transport modes per country, typography, and more. They obtain real emissions data from the customers about shipped weight, do quality checks of the weight and volumes at terminals, and produce reports according to the requests of the customer.

The next segment of questions focuses on obtaining specific information regarding the transportation routes selected for the cases, typical cargo, fuel, and vehicle characteristics and types, reloading practices, and subcontractor involvement (local transportation companies). Subsequent questions involved investigating the details behind emissions calculation methods, the utilisation of carbon footprint calculators, data acquisition processes, and the methodology used for computing the energy consumption and energy chain of Well-to-Tank, Tank-to-Wheel, and Well-to-Wheel. This included which inputs forms the outputs, the calculated emissions, incorporating CO2e, the use of emission standards for emission factors, and other related aspects.

Kuehne + Nagel

Kuehne + Nagel is a German freight forwarding logistics company that have recently started driving for Glamox AS and have taken over from Schenker for certain routes to distribution centres and warehouses in Europe, including UK, Ireland, and The Netherlands. The company have years of experience and subsequently data of flight, sea, and road freight, although road transport is the least accurate. They were unable to disclose the complete routes to Europe, however, alternative truck routes include departures with a boat from Oslo or South of Norway to Denmark, or from Gothenburg in Sweden to Kiel in Germany. Truck routes to the UK might occasionally integrate sea freight, however, the road freight calculations are made based on the total distance and does not separate the use of ferries and boats. The company employ subcontractors with diesel semi-trucks with emission standard of minimum EURO 6 as main used vehicles, and the size of the goods from Glamox determines if it is re-loaded and consolidated with goods from other customers at the terminals.

Kuehne + Nagel is in full alignment with EcoTransIT World (ETW) software as a third-party logistics (3PL) calculator. This alignment involves the submission of data to ETW for the generation of finalised emission reports, which they combine with a self-developed calculator that is under development with average calculations based on experience figures. The collaboration with EcoTransIT enables Kuehne + Nagel of comprehensive calculations of global transport chains across all modes of transport, employing an energy-based bottom-up approach. This approach considers air pollutants, carbon and GHG emissions based on energy requirement, fuel, load factor, emission class, and more. The adherence to the EcoTransIT methodology ensures that the calculations are in compliance with the regulatory standards EN 16258, GLEC, ISO 14064-3:2006 verification, and eventually the new ISO 14083. In addition, this assure that methods behind the calculations are updated, following, and meeting the necessary requirements for validating their reports, and thus, that they offer more accurate and transparent carbon emissions for their clients. Clients have access to their emissions reports on the company's website, and are otherwise presented with a full emissions summary, statistical and detailed data report.

The road calculations follow the customer-specific modelling of EcoTransIT combined with information from Kuehne + Nagel and are based on ETW default standard values where Kuehne + Nagel does not have specific information points. Numerical input includes gross weight in kgs, chargeable weight in kgs, volumes in cubic meters, and total distance in kilometres consisting of collection, linehaul, and distribution, and are acquired by self-measuring methods, subcontractors or calculated by average values. EcoTransIT provide calculations according to the energy chain of WTT, TTW, and WTW, including GHG emissions such as CO_2, NOx, SO_2, and particulate matter (PM10). Kuehne + Nagel adopts CO_2 equivalents (CO_2e) as a metric for the main transport leg(s), calculated using software by Smart Freight Centre in accordance with GHG Protocol, EN 16258, and the GLEC Framework. Kuehne + Nagel expresses that further details and background information of their emissions calculation processes, especially for CO_2e, are strictly confidential.

DHL

The German international logistics company DHL offer Express services for shipments with limited weight and volume. Their supply chain consists of pick-up with small truck or van, road transportation and terminal handling, and delivery with small truck or van. In addition, DHL offer the DHL Economy service for less time-critical shipments within limited weight and dimensions. DHL was unable to disclose details of routing and subsequently truck information, however, they state in a report for DHL Express the use of subcontractors and calculate the routes using country specific Vehicle Operation System (VOS) with various functions for each of their legs along the routes.

DGF (DHL Global Forwarding) is an air freight operator that uses all available cargo and commercial networks and incorporates the use EcoTransIT. DHL Express, on the other hand, is an integrator and predominately relies on its own closed network, owned aircraft fleet, and in-house calculations. DHL Express employs a reporting methodology aligned with the EN 16258 standard and a bottom-up approach, where specific CO_2e emissions are calculated ex-post per shipment as defined in scope 1, 2, and 3 of the GHG Protocol, including the energy chain WTW. Inputs involve weight in tonnes, distance in kilometres, tonne-kilometres, and outputs comprise CO_2e time-to-wheel (TTW) and WTW, as well as energy consumption TTW and WTW. The foundation for their emissions calculation is rooted in emissions derived from operational activities, sourced from actual fuel consumption. Default data from the Handbook Emission Factors for Road Transport (HBEFA) is employed for road transport when specific fuel use data is unavailable. These emissions determine a CO_2e emission factor per kilo, per shipment, or per handled piece, varying across operational modes such as the linehaul sector, pick-up and delivery activities, or facilities.

The network business model of DHL Express is connected to the computation of carbon emissions from customers. The company annually updates their own calculated emission factors, which are calculated for each lane and mode, influenced by country of origin and destination, network routing, trade lane, vehicle, load factor, and fuel type. The shipment route is deconstructed into its components, with a CO2e factor applied to each part of the shipment cycle, sometimes per individual route leg and at other times per country. The DHL Express proprietary emission calculation system applied methodologies and factors are verified annually by independent external auditors Société Générale de Surveillance (SGS), which corresponds to DNV in Norway, for meeting the principles of relevance, accuracy, transparency, completeness, and consistency. DHL expresses that further details and background information of their routes, emission factors, emissions calculation processes, and more, are strictly confidential.

DB Schenker

The global Austrian logistics and transportation company, DB Schenker, offers a comprehensive set of logistics services, including road, rail, air, and sea freight. Historically, they have been the main provider of transportation services for heavy goods transport by road for Glamox to their customers domestically and in Europe. The company use the general heavy goods routes between Norway and Europe by road, where the routes are based on legs. They have their own fleet of vehicles and an internal system tracking vehicle usage on various legs, however, there are challenges in precisely identifying the correct vehicles on the specific routes. In example, two electrical trucks and three diesel trucks are all calculated as diesel, and consequently, they have developed a tool to compute the correct vehicles information.

Until 2019, Schenker operated their own internal calculator but has since transitioned to becoming a client of EcoTransIT and subsequently follow the methodology of EN 16258 and soon the new ISO 14083. Their data is based on average values, such as pre-calculated values from standard values for diesel and are submitted to EcoTransIT using API solutions (application programming interface). Inputs for their calculations include gross weight in tonnes, volumes in cubic metres, fuel consumption, and total distance sometimes divided by collection, linehaul, and distribution distance in km. The output is CO_2 TTW and WTW, CO_2e TTW and WTW, SO_2 WTW, NOx WTW, NMHC WTW, and PM WTW, and does not include general TTW and WTW energy consumption.

Schenker provided limited data information in response to the follow-up questions, however, they specified the use of emission reports from EcoTransIT, which they edit with country-specific details. Notably, adjustments are made to the product code to account for the incompatibility of vehicles and trains within the emission reports.

Important observations

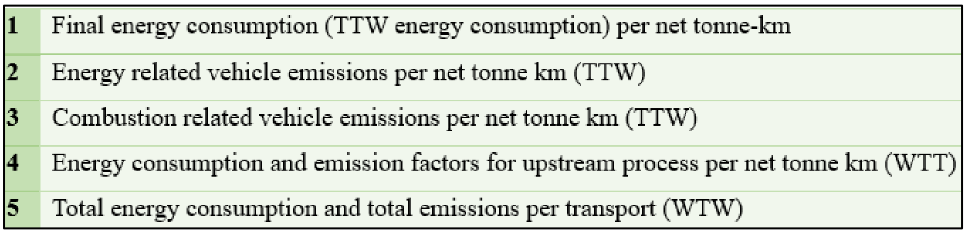
In examining the emission calculation practices of transportation companies, significant findings emerge from the operations of Kuehne + Nagel, DHL, and Schenker. A common thread among these companies is the outsourcing of their emission calculations to EcoTransIT, reflecting a shared reliance on this resource either for primary calculations or as a supplement within their operations. Notably, both Schenker and Kuehne + Nagel exhibit a proactive approach to refining EcoTransIT-generated emission reports, modifying them on various levels to incorporate country-, route- and vehicle specific details. Moreover, certain companies engage subcontractors, introducing an additional level to the emission chain of collecting data, extending from the subcontractor to the end customer. This further implies potential variations and practises in collecting the necessary input data for emissions calculations.

5.7 Self-made carbon footprint calculator for transportation

Carbon footprint calculators are composed tools consisting of many parameters, factors and variables influencing the outcome. In the pursuit of creating a self-made carbon footprint calculator for transportation, I opted to deconstruct, examine, and attempt to recreate the emission reports from EcoTransIT and NTMCalc and the collected data from Schenker.

Starting with the method for calculating fuel consumption and emissions from freight transportation activities, where EcoTransIT is using an energy-based bottom-up approach. This approach involves breaking down the process of energy consumption into detailed components and relies on specific data inputs on a detailed level, such as activity data, fuel and energy consumption per vehicle or activity. In contrast, the common top-down approach allocates aggregated total emissions or energy consumption to specific activities. The basic input needed for the calculations determining the energy emissions stages of WTW and GHG emissions consist of variables for gross weight, transport mode, fuel type, and distance, where distance can be divided into collection, linehaul, distribution and total. Additional data on fuel consumption, vehicle types, and EURO emission standards for road transport are necessary when using the energy-based approach, where the total fuel consumption is dependent on the share of fuel type such as diesel, biofuel, and electricity. Furthermore, the calculations must account for load factors, empty trip factors, and other efficiency metrics specific to the logistics provider. The final calculations are computed with different equations using the inputs combined with default values for emission factors retrieved from the standard EN 16258, HBEFA, and other data source providers . Real-time data from shipments and routes, vehicle types and fuel consumption provided by their customer allow for more accurate emission estimates.

EcoTransIT provide a set of basic calculations rules in their methodology, explaining the five necessary steps of calculating the total energy consumption and emissions of each transport mode for their upstream process (WWT) and vehicle usage (TTW) (ETW 2023):



1	Final energy consumption (TTW energy consumption) per net tonne-km
2	Energy related vehicle emissions per net tonne km (TTW)
3	Combustion related vehicle emissions per net tonne km (TTW)
4	Energy consumption and emission factors for upstream process per net tonne km (WTT)
5	Total energy consumption and total emissions per transport (WTW)

Table 19: Basic calculations rules by EcoTransIT

Each step contains additional steps of equations and information on the needed details that are necessary to compute these, and are briefly explained in the following (ETW 2022):

1. **Final energy consumption TTW:** Details of specific energy consumption, payload capacity, and capacity utilisation of vehicle or vessel per km is needed and must be differentiated for each energy carrier (fuel type) considering different emission factors.
2. **Energy related vehicle emissions TTW:** Details of specific energy consumption per net tonne km and energy related vehicle emission factor per fuel type is needed to compute all emission components that are linked to the final energy consumption (TTW SO_2, CO_2 and CO_2e emissions). Conversion factors of EN 16258 is used.
3. **Combustion related vehicle emissions TTW:** Details of specific emission factor per km, payload capacity and capacity utilisation of vessel or vehicle are needed.
4. **Energy consumption and emission factors WTT:** Details of specific energy consumption of vessel or vehicle per net tonne km and energy related upstream or emission factor per fuel type from EN 16258 are needed.
5. **Total energy consumption or emissions:** Details of transport distance as a result of routing algorithms of ETW and mass of transported freight are needed to be multiplied with the results of combined step 2 TTW and step 4.

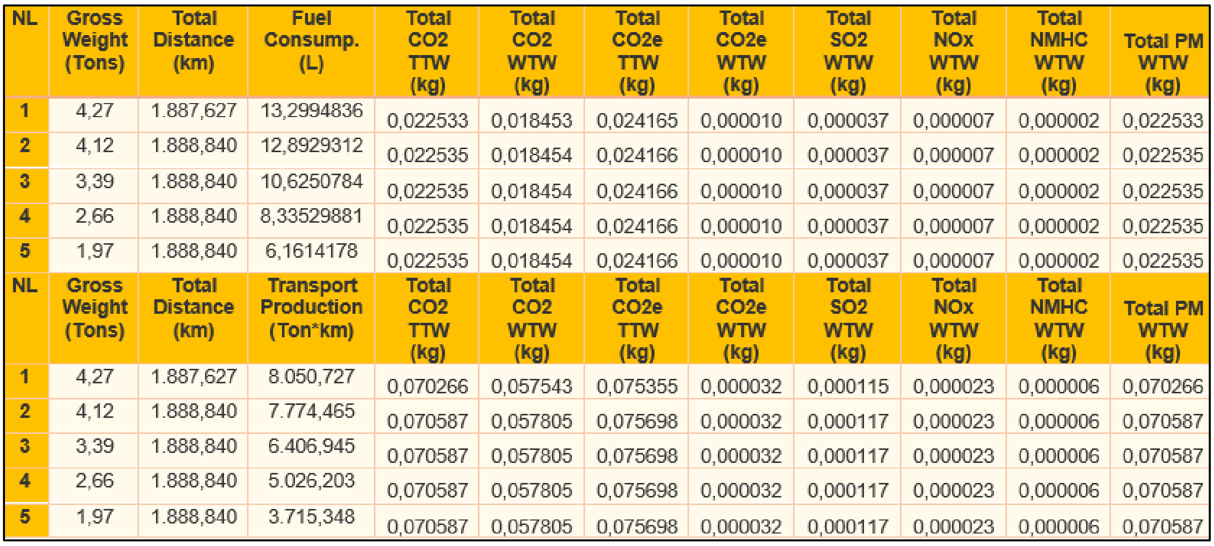
The steps were followed to deconstruct the reports from EcoTransIT, although, it became evident that my results were inadequate and incomplete compared to outputs from the report. Each step required information and specific details which was provided in the methodology to a varying degree, such as specific energy consumption and payload capacity of vehicles, emissions TTW per average diesel truck with different load factors, and an annex of EN 16258 default conversion factors for different fuel types converted to energy factors of TTW and WTW, CO2e-factors, and CO2-factors. An important find was the unit of measurement per emission factor did not always match the description of the unit for each component in the equations. This indicated that to solve the main equations there were additional equations within the main that needed to be solved first, and while this was clear for the capacity utilisation of a vehicle the rest was up to interpretation. The capacity utilisation for my calculations was 50%, computed with an average load factor of 60% and empty trip factor of 20%.

EcoTransIT mentions in their methodology that the WTW emission and energy consumption is dependent on specific details behind the routing, such as gradient, load factor, driving patterns, traffic conditions, country/region specific emission factors, road network resistance, and other road categories, however, they only provide some of the variable index for theses. This indicates that the calculation steps involve numerous influencing factors and uncertainties, making it challenging to ensure that the outcome from a self-made emissions calculator accurately reflects the method of EcoTransIT

NTMCalc describe eight main steps in their general calculation process of road transport, from collecting information about the shipment, selecting vehicle type and load capacity utilisation, finding the distance, setting fuel type and fuel consumption, setting emission factors and energy factor for the fuel, calculating vehicle environmental performance data, compensate for exhaust emissions, and allocation to investigated cargo (NTM 2023a). An important factor for the calculations is the fuel consumption per transport, which is calculated by multiplying the distance with the distance specific fuel consumption corresponding to the load factor, road type, and vehicle. The total fuel consumption is then used to calculate the pollutant emissions by being multiplied with fuel-specific emission factors from the NTMCalc database. Other factors were calculated with factors from EN 16258, HBEFA, and other sources.

The distance specific fuel consumption is provided in the generated reports from NTMCalc reports as fuel consumption in litres per km and was 0,30779547 L/km for 28-34 tonne trucks and 0,4915842892 L/km for 50-60 tonne trucks. The deliveries to the Netherlands with default NTMCalc parameters for a 50-60 tonne truck with average distance of 1.888.840 km were used to calculate the interpreted equation for the fuel consumption, which suggested an average total fuel consumption of 928,524 litres for each delivery. Further calculations in attempts to deconstruct the numbers from the reports and finding the emission factors were inconclusive. Although, some patterns of minor deviations in the calculations suggested that there was a correlation between the distance and the emission outputs.

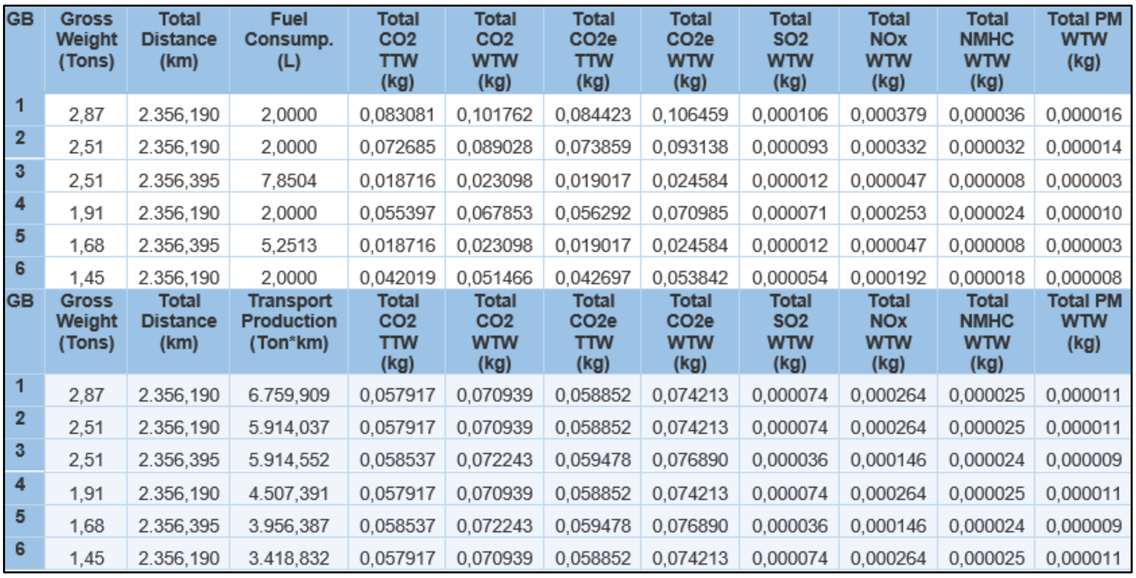
The observation of potential distance correlation could also be found when deconstructing the reports from Schenker, as displayed in an example of deliveries to The Netherlands below. In the first five rows, the value per cell have been calculated as the original emissions value from the report divided by the total distance multiplied with the fuel consumption. In the last five rows, the emission per cell have been calculated as the original emissions value from the report divided by the transport production of tonne-km, which is the gross weight multiplied with the total distance. There results display a clear pattern of the same values per column, with minor deviates for delivery 1, which have a 1,21 km shorter distance. Entering other values for either the distance or the fuel consumption will change the values of the cells in corresponding row.



NL	Gross Weight (Tons)	Total Distance (km)	Fuel Consump. (L)	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	4,27	1.887,627	13,2994836	0,022533	0,018453	0,024165	0,000010	0,000037	0,000007	0,000002	0,022533
2	4,12	1.888,840	12,8929312	0,022535	0,018454	0,024166	0,000010	0,000037	0,000007	0,000002	0,022535
3	3,39	1.888,840	10,6250784	0,022535	0,018454	0,024166	0,000010	0,000037	0,000007	0,000002	0,022535
4	2,66	1.888,840	8,33529881	0,022535	0,018454	0,024166	0,000010	0,000037	0,000007	0,000002	0,022535
5	1,97	1.888,840	6,1614178	0,022535	0,018454	0,024166	0,000010	0,000037	0,000007	0,000002	0,022535
NL	Gross Weight (Tons)	Total Distance (km)	Transport Production (Ton*km)	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	4,27	1.887,627	8.050,727	0,070266	0,057543	0,075355	0,000032	0,000115	0,000023	0,000006	0,070266
2	4,12	1.888,840	7.774,465	0,070587	0,057805	0,075698	0,000032	0,000117	0,000023	0,000006	0,070587
3	3,39	1.888,840	6.406,945	0,070587	0,057805	0,075698	0,000032	0,000117	0,000023	0,000006	0,070587
4	2,66	1.888,840	5.026,203	0,070587	0,057805	0,075698	0,000032	0,000117	0,000023	0,000006	0,070587
5	1,97	1.888,840	3.715,348	0,070587	0,057805	0,075698	0,000032	0,000117	0,000023	0,000006	0,070587

Table 20: Deconstructed Schenker report for deliveries to The Netherlands

The same calculations were done using deliveries to England, as illustrated in the table below. However, the results did not display the same overall unison patterns compared to The Netherlands. This might be because of the use of default fuel consumption value of 2 L for delivery 1, 2, 4, and 6, whereas delivery 3 and 5 displayed similar calculated values per column. The results present a clear deviation with the use of default fuel consumption values of 2 litres in contrast to specific fuel information. The overall results from dividing by tonne-km presents a clear pattern of the same values in each column in accordance with the same total distance used, with smaller deviations in total distance for delivery 3 and 5.



GB	Gross Weight (Tons)	Total Distance (km)	Fuel Consump. (L)	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	2,87	2.356,190	2,0000	0,083081	0,101762	0,084423	0,106459	0,000106	0,000379	0,000036	0,000016
2	2,51	2.356,190	2,0000	0,072685	0,089028	0,073859	0,093138	0,000093	0,000332	0,000032	0,000014
3	2,51	2.356,395	7,8504	0,018716	0,023098	0,019017	0,024584	0,000012	0,000047	0,000008	0,000003
4	1,91	2.356,190	2,0000	0,055397	0,067853	0,056292	0,070985	0,000071	0,000253	0,000024	0,000010
5	1,68	2.356,395	5,2513	0,018716	0,023098	0,019017	0,024584	0,000012	0,000047	0,000008	0,000003
6	1,45	2.356,190	2,0000	0,042019	0,051466	0,042697	0,053842	0,000054	0,000192	0,000018	0,000008
GB	Gross Weight (Tons)	Total Distance (km)	Transport Production (Ton*km)	Total CO2 TTW (kg)	Total CO2 WTW (kg)	Total CO2e TTW (kg)	Total CO2e WTW (kg)	Total SO2 WTW (kg)	Total NOx WTW (kg)	Total NMHC WTW (kg)	Total PM WTW (kg)
1	2,87	2.356,190	6.759,909	0,057917	0,070939	0,058852	0,074213	0,000074	0,000264	0,000025	0,000011
2	2,51	2.356,190	5.914,037	0,057917	0,070939	0,058852	0,074213	0,000074	0,000264	0,000025	0,000011
3	2,51	2.356,395	5.914,552	0,058537	0,072243	0,059478	0,076890	0,000036	0,000146	0,000024	0,000009
4	1,91	2.356,190	4.507,391	0,057917	0,070939	0,058852	0,074213	0,000074	0,000264	0,000025	0,000011
5	1,68	2.356,395	3.956,387	0,058537	0,072243	0,059478	0,076890	0,000036	0,000146	0,000024	0,000009
6	1,45	2.356,190	3.418,832	0,057917	0,070939	0,058852	0,074213	0,000074	0,000264	0,000025	0,000011

Table 21: Deconstructed Schenker report for deliveries to England

5.8 Uncertainty

The use of carbon footprint calculators introduces a range of uncertainties that impact the accuracy and reliability of the calculated emissions. The analysis for both quantitative and qualitative results depict intricate factors that contribute to potential inaccuracies associated with carbon footprint assessments. Quantitative uncertainties involve issues of accessibility, precision, and variability of data sources, emission factors, and the absence of standardised methodologies. Variability in the methodologies and data sources employed by the calculators leads to variations in the final quantifications. The calculation process relies on numerous assumptions and default average values for parameters such as capacity utilisation, fuel consumption, distance, and emission factors, which may not accurately represent real-time regional or individual circumstances. The emission factors are responsive to dynamic changes in technology, fuel types, and evolving emission standards.

The involvement of subcontractors introduces uncertainties in securing consistent and transparent data, given different practices, measurement standards, technology levels in data collection, and subsequently, divergent data sets. Qualitative uncertainties encompass contextual factors influencing carbon footprint calculations and the adaptability of these assessments to operational landscapes shaped by industry practices and policy nuances. In addition, the human factor of interpretation introduces potential variations in the application of the calculation tools.

6.0 Conclusion

The thesis explores the complexities surrounding carbon footprint calculations for freight transportation, focusing on the challenges faced by manufacturers outsourcing their transportation, with Glamox as a specific case study. The increasing global concern for greenhouse gas emissions motivates companies to seek solutions for how they can measure their environmental impact. Commercially available carbon footprint calculators are presented as comprehensive tools for calculating emissions from freight transportation, widely used by companies globally. However, variations in standards and methods across the market of these calculators presents uncertainties in the accuracy and transparency of the overall use of outsourced calculators. This concern is further addressed in the subsequent section of answered research questions.

RQ1: Why do companies engage in carbon emissions measurement and reporting?

Companies engage in emissions measurement and reporting as a strategic response to internal and international policies aimed at reducing carbon footprints. Motivations include individual strategic sustainability objectives to embrace environmental responsibility in the industry, compliance with emission reduction commitments targets, and a growing demand from customers for documentation and transparency of their emissions. The qualitative data collection highlights variations in policies among transportation companies in balancing confidentiality and transparency toward clients, influencing the extent to which they disclose operational details while preserving sensitive information.

RQ2: How do transportation companies calculate and report their carbon emissions for road transport?

Transportation companies employ a variety of methods and processes to calculate and report carbon emissions, particularly in the context of road transport. These approaches involve intricate steps and considerations, including data collection, choice of emission calculators, and the integration of influencing factors of vehicle type, fuel types, emission standards, and more. The companies employ different practises when collecting the input data, with some relying on their own fleet of vehicle or engaging subcontractors, which suggest potential variations in the acquired data. The calculations require specific inputs such as gross weight, volumes, fuel consumption, and total distance, with adjustments made for factors like load capacity, empty trip considerations. The involvement of outsourced external tools as EcoTransIT is a frequent practice to varying degrees among the transportation companies included in this study. However, certain companies engage in refining these outputs to align them more closely with specific operational nuances in the company. In addition, they invest in developing in-house models and collects in real-time data from customers for more accurate emission estimates.

RQ3: How consistent and replicable are the emissions calculations by transport companies for road transport compared to commercially available calculators?

The assessment of the consistency and replicability of emissions calculations by transport companies reveals several uncertainties. The quantitative analysis displays notable variations and discrepancies in the results comparing the collected data from the transportation company to replicated versions using the online calculator tools of EcoTransIT and NTMCalc. The deviations are attributed to the multitude of factors affecting the calculations, including variability in methodologies, data sources, emission factors, undisclosed values for certain parameters, and assumptions of default average values. This was accentuated by the limited transparency for certain details in the challenge of creating a self-made calculator based on methodologies of established carbon footprint calculators. The overall uncertainties surrounding the key input parameters of routes, emission standard, load factor, empty trip factor, vehicle type, and precise fuel consumption, impacts the output and comparability of the results. In addition, the refinement process by the transportation companies for the externally generated reports introduce a level of subjectivity and potential inconsistencies to the reports.

RQ4: Does a carbon footprint calculator function as an accurate tool for measuring a manufacturers carbon footprint from transportation? Why/why not?

Carbon footprint calculators offer valuable insights for manufacturers, relying on various scientific methods that are regularly updated. However, the reliability and accuracy of these tools is influence by several factors such as the level of details for the input data quality and precision, as indicated by deviations in the quantitative analysis. An example from deliveries to England with Schenker highlights potential default values in fuel consumption. Diverse practices in methodologies, such as regional variations in emission factors and undisclosed calculations for specific traffic, gradient, driving patterns, and other country factors, contribute to accuracy challenges. The qualitative data accentuates potential limitations in providing fully accurate measurements due to real-world complexities of transportation operations and transparency, leading to uncertainties in outputs. Moreover, the increase of electric vehicles and other advancements in transportation technology may not be accurately captured in the calculations, exemplified by Schenker basing route calculations on average values between electric and diesel vehicles.

7.0 Future research

The assessment of carbon footprint calculators represents an extensive topic, and the scope of this thesis was therefore limited to comparing collected data from transportation companies with online tools. This was further limited to road freight transportation for less complexity. For future research of carbon footprint calculators, a recommended approach involves revisiting the original plan for this thesis, which was presented in the chapter for methodology. This entails creating a case study where all participating transportation companies receive identical inputs to generate emissions reports and analyse the differences, facilitating a more robust basis for comparison and enhancing the reliability and validity of the research findings. Another path for future research is the comparative examination of differences between the older standard EN 16258 and the recent ISO 14083 in the forthcoming years.

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