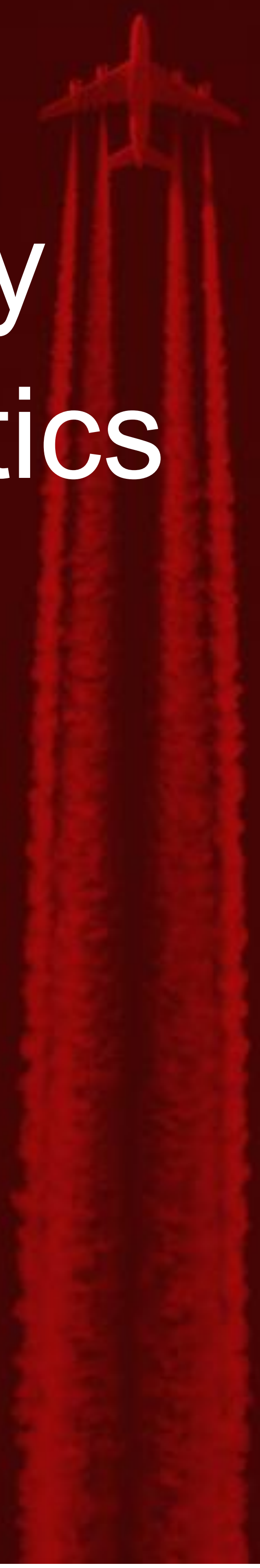
Smart Freight Centre

15 October 2025

Air Pollutant Emissions

Methodology for the logistics sector



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Smart Freight Centre (SFC) is a globally active non-profit organization for climate action in the freight sector. Our goal is to mobilize the global logistics ecosystem, in particular our members and partners, in tracking and reducing its GHG emissions. We accelerate the reduction of logistics emissions to achieve a zero-emission global logistics sector by 2050 or earlier, consistent with 1.5° pathways.

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Finally, we acknowledge all contributors who provided insights, feedback, and technical input during the development of this report. Their engagement has helped ensure that this updated methodology serves as a practical, credible, and forward-looking tool for the logistics sector.

Contents

List of abbreviations

BaU	Business-as-Usual
BC	Black Carbon
CAF	Clean Air Fund
CCAC	Climate and Clean Air Coalition
CCD	Climb/Cruise/Descent
CDP	Carbon Disclosure Project
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSRD	Corporate Sustainability Reporting Directive
DAF	Distance Adjustment Factor
EEA	European Environment Agency
EF	Emission Factor
EMEP	European Monitoring and Evaluation Programme
FC	Fuel Consumption
FI	Fuel Intensity
GCD	Great Circle Distance
GHG	Greenhouse Gases
GLEC	Global Logistics Emissions Council
HDV	Heavy Duty Vehicle
ICCT	International Council on Clean Transportation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
LCV	Light Commercial Vehicle
LF	Load Factor
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTOs	Landing and take-off operations
LT	Load Transported
MJ	Megajoule
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
N_2O	Nitrous Oxide
NFR	Nomenclature For Reporting
$PM_{10}/PM_{2.5}$	Particulate Matter with aerodynamic diameter ≤ 10 µm / ≤ 2.5 µm
SBTi	Science-Based Targets initiative
SEI	Stockholm Environment Institute
SFD	Shortest Feasible Distance
SO_x	Sulphur Oxides
tkm	Tonne-kilometre (freight transport activity unit)
TOC	Transport Operation Category
TSP	Total Suspended Particulates

Executive summary

The term ‘air pollutant’ covers a wide range of chemical compounds whose release into the atmosphere can harm human health, ecosystems, and the climate. The World Health Organization (WHO) identifies air pollution as one of the most critical environmental health risks, reporting that around 99% of the global population is chronically exposed to concentrations exceeding its guideline thresholds. Beyond health risks, certain air pollutants can drive short-term warming, disrupt precipitation patterns, cause acid deposition, degrade soil quality, and reduce agricultural productivity. The impacts of these pollutants translate to a significant social, environmental, and economic burden.

Transport-related air pollutant emissions consist of a complex mix of gases and particulate matter produced by vehicles through both exhaust processes (e.g., fuel combustion) and non-exhaust sources (e.g., brake and tyre wear). Addressing air pollution presents a strategic opportunity for the logistics sector to reduce emissions and accelerate decarbonisation, since sources of air pollutants often overlap with those of greenhouse gases (GHGs). By taking action, organisations can get ahead of emerging regulatory requirements, pinpoint emission hotspots across their value chains, and implement targeted mitigation strategies.

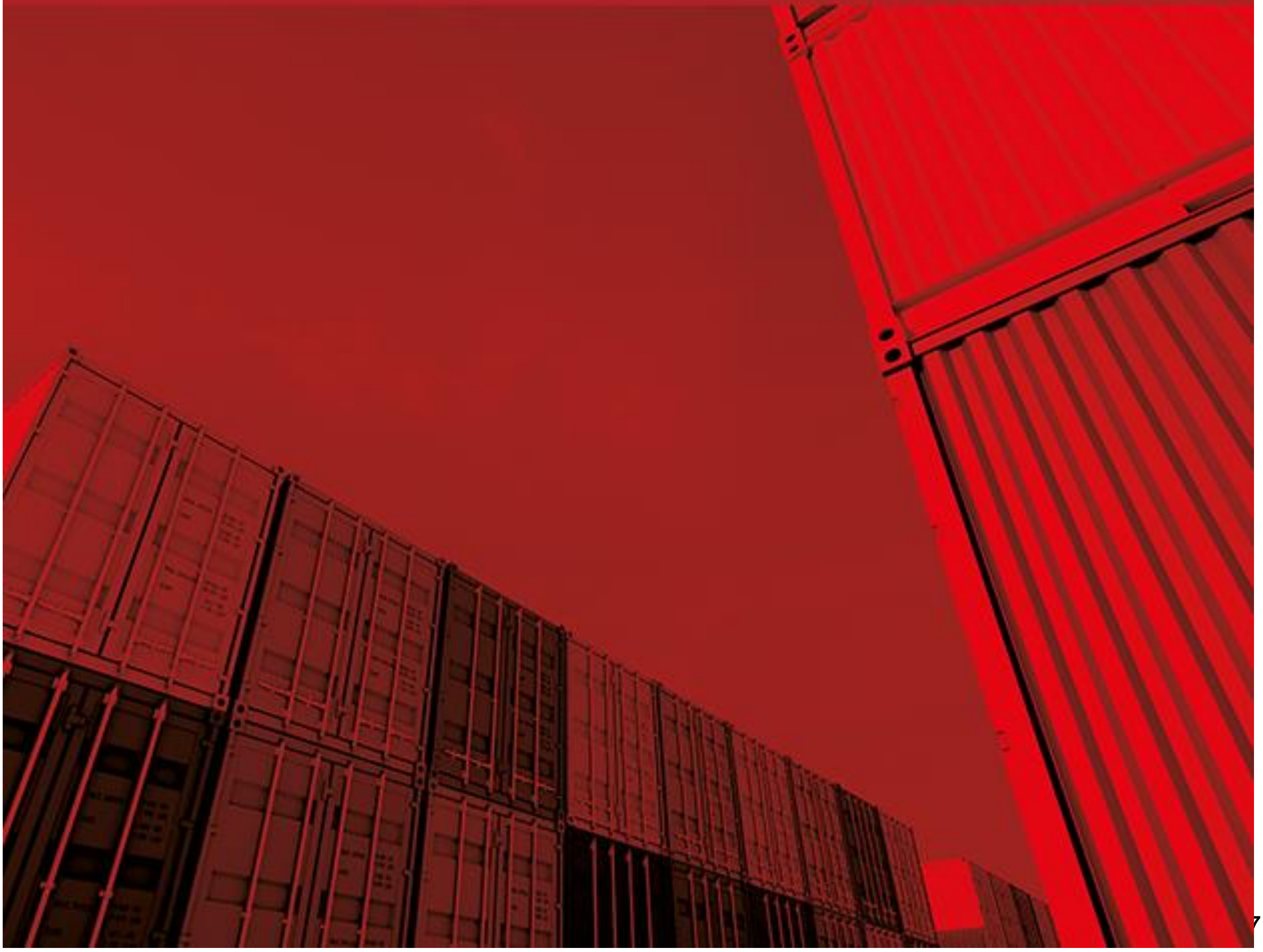
Although advances in sustainable technologies are reducing the sector’s overall environmental footprint, the quantification and reporting of air pollutant emissions remain under addressed. A key barrier has been the lack of widely available methodologies for calculating these emissions, which limits understanding of their magnitude and sources and subsequently the ability to mitigate impacts through real-world interventions.

The GLEC Framework presented methods to estimate black carbon (BC) emissions through its ‘Black Carbon Methodology for the Logistics Sector’ (2017). Building on this foundation, Smart Freight Centre (SFC) is now updating the methodology in collaboration with the Stockholm Environment Institute (SEI). This revision integrates elements from both the Black Carbon Methodology and the Climate and Clean Air Coalition’s (CCAC) and SEI’s ‘Integrated Guide for Business Greenhouse Gas (GHG) and Air Pollutant Emission Assessment’ (2025). In doing so, it not only refines and strengthens calculation methods for black carbon emissions but also expands the scope to include other air pollutants, such as nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter ($PM_{2.5}$ and PM_{10}).

Developing a comprehensive emissions inventory is a critical first step toward quantifying pollutant emissions, identifying major sources, and designing effective strategies to mitigate environmental and public health impacts. This guidance aims to equip users with clear methods for quantifying air pollutant emissions across all modes of transport within the freight and logistics sector. Section 1 of this document will give an overview of the importance and impacts of air pollution, Section 2 will focus on the available methods for the different modes of transport (road, non-road, rail, aviation and shipping) and Section 3 provides further information for the inventory compiler including best practice on how to compile the inventory.

1

Introduction



1. Introduction

Transport is an essential and critical component across many value chains, but it is also one of the key sources of greenhouse gas (GHG) and air pollutant emissions [1,2]. While advances in engine design, fuels, and technologies are reducing the impact road, rail, shipping, and air freight have on the environment, the quantification of air pollutant emissions across the different modes of transport is still relatively new for the private sector. This, however, is a very critical first step for the private sector to understand the magnitudes of air pollutants emitted, the key emitting sources, and consequently where action can be taken to reduce air pollutant emissions.

The aim of this document is to provide companies and relevant stakeholders with the appropriate methods to quantify air pollutant emissions, specifically particulate matter (PM_{10}, $PM_{2.5}$), black carbon (BC), sulphur oxides (SO_x), and nitrogen oxides (NO_x) from modes of transport including road, non-road mobile machinery, rail, shipping and aviation which will allow them to develop freight and logistics emission inventories across a business's value chain.

The document is intended for carriers, logistics service providers, shippers, and other users assessing freight and logistics across their value chain. It is also useful for end-users of emissions information including governments, investors, and green freight programs. This supports organisations at different stages of emissions accounting, offers guidance for policymakers, and enables informed decisions in investment, procurement, and operations.

The transport and logistics sector already involves a broad range of stakeholders applying the Global Logistics Emissions Council (GLEC) Framework, which has supported organisations in accounting, tracking, and reporting GHGs. The GLEC Framework is the most widely used industry methodology for logistics emissions calculation adopted by over 200 multinational companies, is fully harmonised with ISO 14083:2023 [3]. The Framework is also recognised by the Greenhouse Gas Protocol and is the recommended method for reporting logistics emissions to the Carbon Disclosure Project (CDP) and for aligning targets with the Science-Based Targets initiative (SBTi).

This ***'Air Pollutant Emissions Methodology for the Logistics Sector'*** guidance document provides stakeholders with the opportunity to move beyond GHG reporting by quantifying and incorporating air pollutant emissions into their sustainability (or other types of) reports and assessments. By doing so, organisations can:

1. Understand the magnitude of air pollutant emissions across their value chains and different parts of their operations
2. Consider how their existing decarbonisation strategies can impact air pollutant emissions
3. Anticipate and prepare for emerging regulatory requirements.

The level of attention and priority given to air pollutants in national and international targets and goals has risen significantly. At a regional level, the United Nations Economic Commission for Europe (UNECE) established the Convention on Long-range Transboundary Air Pollution (LRTAP) in 1979 to facilitate cooperation between countries to reduce pollutants that cross borders, setting protocols, monitoring emissions, and guiding policy to protect human health and ecosystems. More recently, the European Union has required member states of the EU-27 to meet limits and target values for concentrations of pollutants under the Ambient Air Quality Directives, and to achieve emission reductions for NO_x, SO_2, NMVOCs, NH_3, and $PM_{2.5}$ through the National Emission Reduction Commitments Directive [4].

At the national level, Nationally Determined Contributions (NDCs) are the climate pledges countries submit under the Paris Agreement (2015), outlining their plans to reduce greenhouse gas emissions and adapt to climate impacts in support of the Agreement's goal of keeping global warming well below 2°C and pursuing efforts to limit it to 1.5°C. More than 60 countries are

currently explicitly acknowledging the importance of air pollution mitigation in their post-2020 NDCs, a substantial increase from approximately 36 countries in the pre-2020 NDCs [5].
In March 2024, the United Nations Environment Assembly (UNEA-6) passed a global resolution calling for increased regional cooperation as well as the development of national programmes, policies, and standards [6]. Finally, in June 2025, the Intergovernmental Science-Policy Panel on Chemicals, Waste and Pollution (ISP-CWP) was established as a new, independent intergovernmental body to address the ways in which science-based policymaking can tackle pollution [7].

And while air pollution has become an important focus area at the local, national, regional and global level, air pollutant emissions from the private sector are poorly quantified despite the important role that operations from the private sector play.

Operations at different parts of a company's value chain will be responsible for emitting air pollutants and it is extremely important for the private sector to actively quantify the air pollutant emissions from these. Since key emitting sources can vary within a company's value chain, the location of emissions will determine which populations are most exposed, with lower-income countries and vulnerable communities typically bearing the greatest burden. 716 million of the world's lowest income people live in areas with unsafe levels of air pollution, especially in Sub-Saharan Africa [8].

1.1 The importance of air pollution

According to the World Health Organization (WHO), ambient (outdoor) air pollution was responsible for approximately 4.2 million premature deaths globally in 2019, with an estimated 89% of these deaths occurring in low- and middle-income countries [9].

Air pollutants consist of different chemical compounds that can adversely affect human health and the environment. This can happen through direct emissions of these pollutants into the atmosphere from a source without undergoing any chemical transformation, or once emitted, these compounds may undergo physical and chemical changes in the atmosphere, creating new substances with additional impacts (secondary formation). Air pollutant emissions can vary in quantity, emitting sources, but they can also greatly vary in terms of the impacts they have on health, climate and the environment [10]. The guidance and available methods in Section 2 will only be covering the quantification of air pollutants that have been directly emitted into the atmosphere.
Air pollution and climate change are closely interconnected. Many air pollutants have an impact on climate and share common sources (Figure 1) with GHGs, particularly from the combustion of fossil fuels. Short-Lived Climate Pollutants (SLCPs) (pollutants with relatively short atmospheric lifetimes) including black carbon, ozone, methane, and hydrofluorocarbons (HFCs), are highly potent climate forcers.

Sources of air pollutant emissions include electricity consumption, stationary fuel combustion, industrial processes, transport, agriculture, and waste. Regarding air pollutant emissions from transport, pollutants like particulate matter, black carbon, sulphur oxides and nitrogen oxides are of particular interest because of their impacts on health, and, in the case of black carbon because of its role as a short-lived climate forcer.

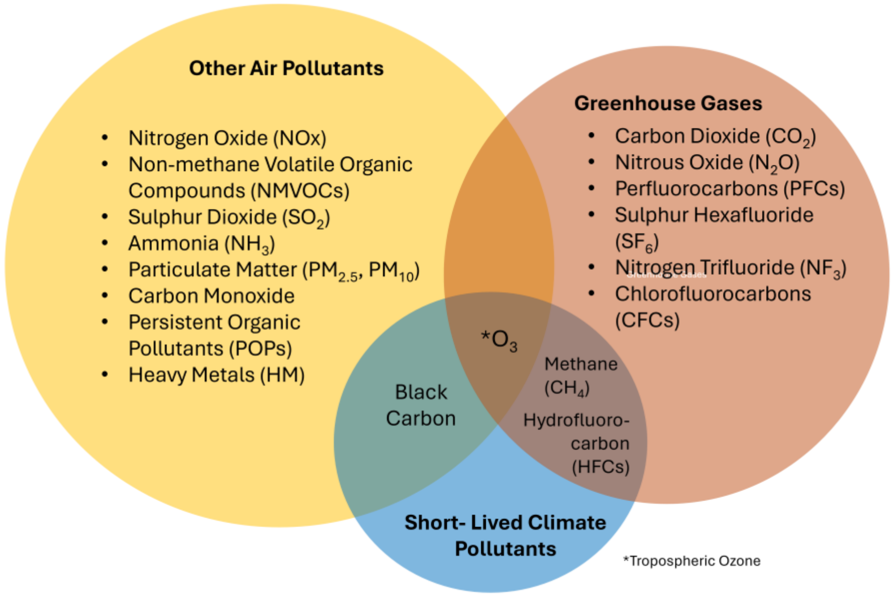


Figure 1 Categorisation of emissions and linkages to key air pollutants. [Source: CCAC and SEI, 2025]

1.2 List of pollutants covered in the guidance

As mentioned above, this guidance is focusing on particulate matter (PM_{10}, $PM_{2.5}$), black carbon (BC), sulphur oxides (SO_x), and nitrogen oxides (NO_x), due to their impacts on health and/or climate [11]. But it must be highlighted that these are not the only pollutants emitted from transport, and for a complete list of air pollutants and heavy metals emitted to the atmosphere from transport the user should visit the EMEP/EEA guidebook (2023)[12].

Particulate Matter (PM)

A significant component of air pollution from vehicles, particulate matter (PM) is recognised for its harmful effects on both human health and the environment. Common nomenclature represents particulate matter as PM_{10} and $PM_{2.5}$, where particles have a diameter of 10 µm and 2.5 µm, respectively, allowing them access to sensitive lung tissue and the bloodstream via absorption. PM can be found in the atmosphere through direct emissions (primary PM), and formation through chemical interactions involving gaseous precursors (secondary PM). Anthropogenic sources of PM include vehicular emissions, road dust resuspension, stationary combustion processes, industrial activities, waste incineration, and construction operations. Among these, vehicular emissions are typically the dominant contributor to PM levels in urban environments. This source includes both exhaust and non-exhaust emissions (e.g., brake wear, tyre wear, and road surface abrasion) and plays a major role in deteriorating urban air quality [13].

Black Carbon (BC)

A major component of PM, black carbon (BC) is recognised as one of the most powerful short-lived climate forcers, exerting a radiative forcing per unit mass approximately 460 to 1,500 times greater than that of CO_2 [14], with a short atmospheric lifetime (approximately 4-12 days), mitigation of BC emissions can deliver rapid climate and environmental benefits, including immediate reductions in radiative forcing and improvements in air quality [15].

The heating effect of BC is primarily due to its strong ability to absorb solar radiation, thereby directly influencing atmospheric temperatures. In addition to its atmospheric warming effect, the deposition of BC on ice and snow-covered surfaces reduces their ability to reflect sunlight, thereby enhancing solar energy absorption and accelerating melting. Due to their ultrafine size, BC particles can remain airborne for extended periods and, while most settle within days, effective lifetimes can sometimes approach several weeks, allowing transport over hundreds to thousands of kilometres [15]. BC also adversely affects agricultural productivity and ecosystem health, acting as a light blocker and raising the temperature of plant leaves when deposited, potentially impairing physiological processes [14].

The main anthropogenic sources of BC include stationary diesel engines, spark-ignition engines, power generation facilities, industrial and commercial boilers, and a variety of residential combustion sources. These residential sources encompass oil furnaces, cookstoves, open fires, fireplaces, woodstoves, and open biomass burning. In urban settings, traffic-related emissions represent a significant proportion of BC. Emissions from vehicular sources are influenced by multiple factors, such as engine type, the presence or absence of exhaust aftertreatment technologies (e.g., particulate filters), traffic density, fleet composition, driving behaviour (e.g., acceleration, idling, braking), road conditions, frequency of stops at intersections, and the mechanical condition and maintenance of vehicles [15].

Sulphur Oxides (SO_x)

Sulphurous oxides are abbreviated as SO_x to represent commonly released SO_2 or SO_3. These chemically reactive gases pose significant risks to human health, animals, and vegetation due to the formation of sulphurous acid, which is one of the main contributors to acid rain. The resulting acidic precipitation, whether in the form of rain, fog, or snow, leads to the acidification of soil and aquatic ecosystems. This can significantly reduce soil fertility, harm aquatic life, impair plant growth and survival, and damage anthropogenic infrastructure [17].

SO_x emissions primarily originate from the combustion of sulphur-containing fuels such as coal, oil, natural gas, or biomass. The sulphur these contain reacts with oxygen to form SO_2. The amount of SO_x emitted depends largely on the sulphur content of the fuel and the efficiency of the combustion process. In the transport sector, maritime shipping has historically been the dominant source of SO_x emissions [2]. Before the International Maritime Organization (IMO) introduced the global sulphur cap in 2020 [18], most large ocean-going vessels operated on heavy fuel oil (HFO), a high-sulphur residual fuel that also produces significant emissions of NO_x and CO_2[18]. Although most ships today use very low sulphur fuel oil (VLSFO) to comply with the new sulphur limits, maritime transport remains the leading contributor to SO_x emissions within the transport sector [2].

Nitrogen Oxides (NO_x)

Among the various oxides of nitrogen (collectively referred to as NO_x) present in the atmosphere, NO_2 is considered the most harmful. It is a highly toxic, non-flammable gas characterised by a sharp, acrid odour and a distinctive brownish red colour [19]. NO_2 plays a central role in the formation of photochemical smog, particularly in urban areas with high vehicle emissions and industrial activity. Its presence contributes to the development of the characteristic brownish haze often observed in polluted city air, which poses serious health risks and reduces atmospheric visibility. The formation of nitrous and nitric acids is also a contributor to acid rain as noted above, further impacting ecosystems through the acidification of soil and water bodies [17].

NO_x compounds are primarily formed during high-temperature combustion processes via the oxidation of both nitrogen compounds in the fuel and atmospheric nitrogen. The main sources of NO_x to which humans are exposed include road transportation, followed by emissions from air and water transport, as well as off-road heavy machinery. Significant additional sources include the energy sector, manufacturing industries, and construction activities. Both SO_x and NO_x play key roles in the formation of secondary pollutants, such as particulate matter [17].

1.3 Health Impacts of Air Pollution

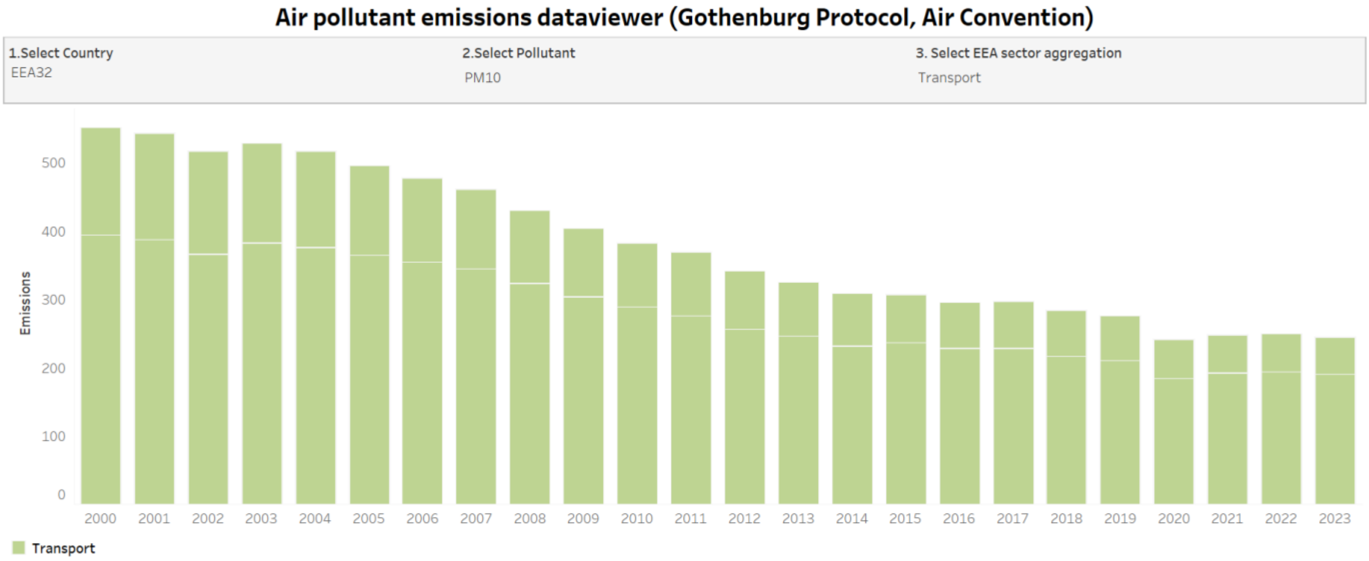
Exposure to PM, especially fine particles such as $PM_{2.5}$, has been associated with a range of adverse health effects, especially among vulnerable populations such as the elderly and individuals with pre-existing respiratory conditions. Due to their small aerodynamic diameter, these particles can penetrate deep into the respiratory tract and enter the bloodstream via absorption, facilitating the transport of harmful compounds throughout the body [20]. Numerous studies have identified a causal relationship between traffic-related air pollution and the incidence of asthma, particularly in children and individuals living near major roadways [21,22]. The severity of health impacts is influenced by both the concentration of airborne PM and the duration of exposure. Chronic exposure to elevated PM levels has been linked to increased risks of cardiovascular events, respiratory diseases, and long-term mortality [17].

Of particular concern is the carbonaceous fraction of PM, specifically BC, as studies have indicated a higher correlation of BC with health problems compared to the $PM_{2.5}$, suggesting BC can promote oxidative stress and inflammation in respiratory and cardiovascular tissues and cause premature death [23]. The health impacts associated with air pollution also result in substantial economic costs, including increased healthcare expenditures and reduced labour productivity [24].

Exposure to either SO_x or NO_x has been strongly correlated with a range of respiratory disorders, including acute episodes of dyspnea (shortness of breath), mucosal membrane irritation, and pleuritic chest pain. NO_x compounds are classified as hazardous atmospheric pollutants. Short-term exposure to nitrogen-based gases has been linked to an increased incidence of respiratory infections and heightened sensitivity to allergens. Furthermore, exposure to fine PM and nitrogen compounds is associated with approximately 40,000 premature deaths annually in the United Kingdom [17].

1.4 Air pollutant emissions from transport

In 2022, the transport sector in the EU-27 accounted for 29.3% of total $PM_{2.5}$ emissions, 26.2% of PM_{10}, 18.8% of BC, 19.2% of SO_x, and 56.5% of NO_x. Road transport was the dominant source of $PM_{2.5}$, BC, and NO_x emissions, while maritime transport represents the largest contributor to SO_x emissions [2]. Figure 2 shows data on particulate matter (PM_{10}) from transport for the EEA32 countries between 2000 and 2023 (top), and PM_{10} data for the same countries during the same period for the transport, energy and waste sectors (bottom).



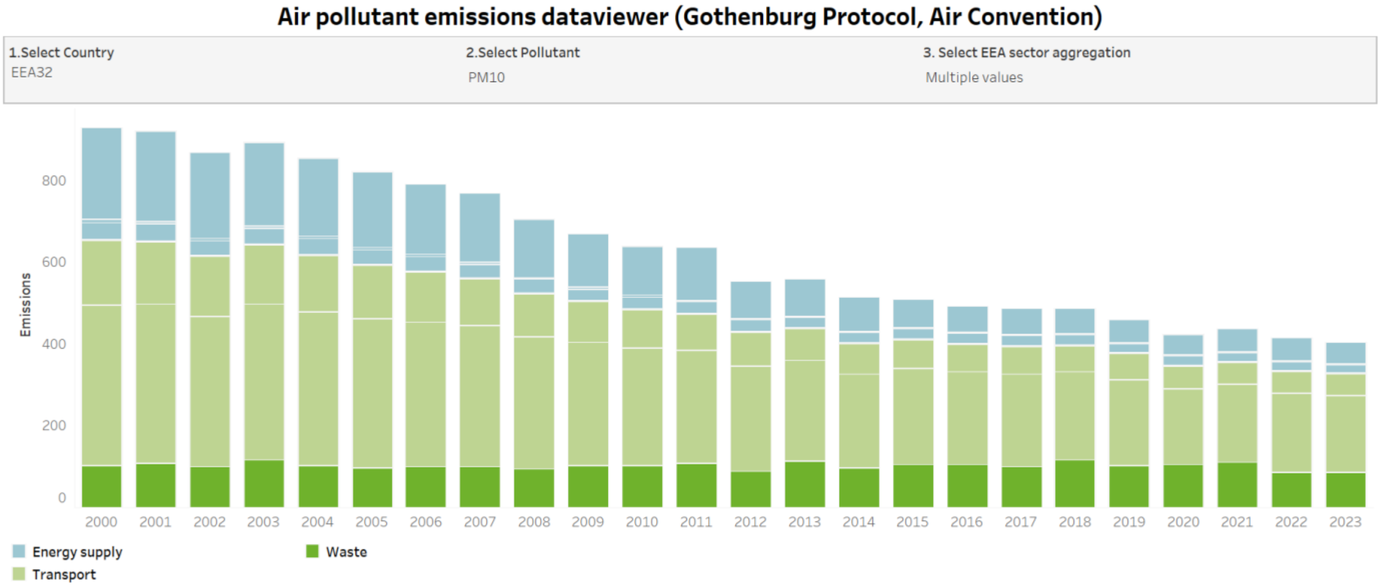


Figure 2 EEA data for the PM_{10} emissions from transport (top), and comparison between energy supply, waste, and transport (bottom)

Strategies to reduce GHG emissions from transport (e.g., improving fuel economy, fuel switch, optimising logistics) will often also reduce air pollutant emissions like nitrogen oxides (NO_x) and tailpipe particulate matter (PM), since GHGs and air pollutants are emitted from fuel combustion. However, there are important nuances that need to be considered as some mitigation measures may not reduce both GHG and air pollutant emissions. For example, certain biofuels can lower GHG but may increase NO_x emissions depending on the engine type, and while electric vehicles eliminate tailpipe emissions, non-exhaust PM emissions from tyre and brake wear remain.

Efforts to reduce air pollutant emissions can also enhance efforts to improve health and reduce the impact of other climate impacts, commonly resulting in policy and mitigation crossover e.g., air quality management policies that control $PM_{2.5}$ are also used in conjunction with tailpipe emissions standards, fuel quality standards, and other related policies.

In the coming years, transport-related emissions are projected to decline in some regions while increasing in others [25]. In high-income countries for example, emissions of $PM_{2.5}$ are expected to continue decreasing due to the adoption of advanced vehicle technologies and the widespread use of cleaner, low-sulphur fuels. Conversely, in low- and middle-income countries, emissions are anticipated to rise as transportation demand grows, and outdated technologies remain prevalent [26].

1.5 The Purpose of this Document

The purpose of this document is to offer technical guidance, methods and emission factors to the transport and logistics sector that will enable the quantification of air pollutant emissions, e.g., particulate matter (PM_{10}, $PM_{2.5}$), BC, NO_x, and SO_x.

Methods and emission factors are available for the following modes of freight transport: road, non-road mobile machinery, rail, shipping and aviation, to cover exhaust emissions from a range of fuels and technologies. As illustrated in Figure 3, the scope of this methodology is limited to exhaust emissions (i.e., emissions occurring from the combustion of fuels in the engines of mobile sources), and does not cover non-exhaust emissions (i.e., evaporation of fuel or tyre and brake wear).

For sources not covered by this methodology (i.e., emissions from electricity consumption, stationary fuel combustion, industrial processes, agriculture and waste), users may refer to other resources such as the CCAC/SEI Guide for Emission Assessment (2025).

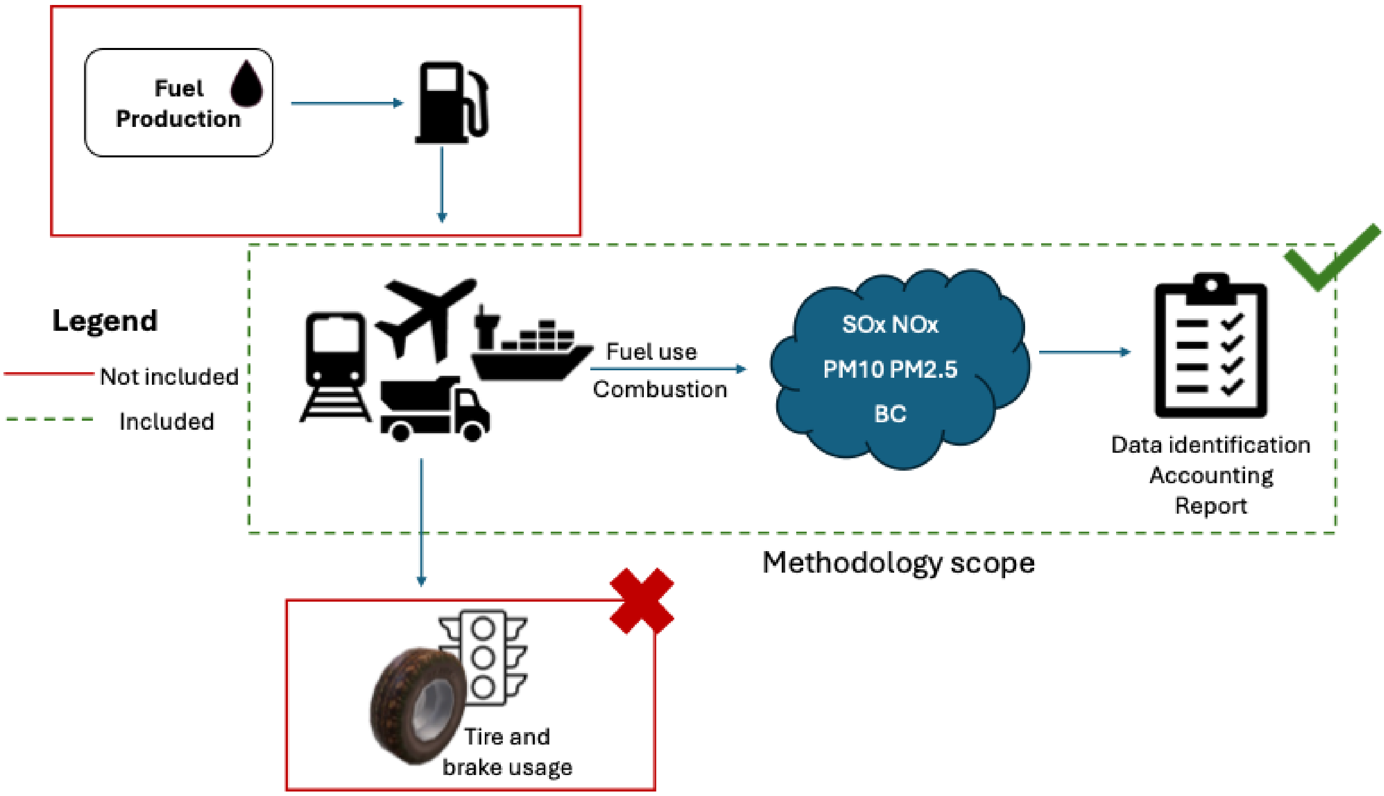


Figure 3 System Boundaries of the Methodology: Included and Excluded Emission Sources

The methods and guidelines provided in this document can support companies aiming to assess, report, or integrate their air pollutant emissions data into sustainability reporting. While such reporting is mandatory under the Corporate Sustainability Reporting Directive (CSRD) and European Sustainability Reporting Standard on Pollution (ESRS E2), organisations may omit air pollution if they deem it non-material. When air pollutant emissions are considered material to a company, or when quantification of emissions is needed for internal reporting, the guidance provided here enables organisations to produce emissions inventories aligning with emerging expectations, improving transparency, and strengthening the integration of air quality considerations into corporate reporting frameworks.

ISO 14083:2023 [3] establishes a robust methodology for quantifying GHG emissions from transport chain operations and includes an informative Annex addressing black carbon emissions, it does not comprehensively address other critical air pollutants that significantly impact human health and environmental quality.

This guidance extends the methodological scope beyond the GHGs to include additional air pollutants such as particulate matter (PM_{10}, $PM_{2.5}$), sulphur oxides (SO_x), and nitrogen oxides (NO_x), thereby supplementing existing standards to enable a more comprehensive assessment of transport-related air pollutant emissions. This extended methodology is aligned with the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2023[12] and the CCAC/SEI Integrated Guide for Businesses (2025) [10], while maintaining alignment with the GLEC Framework [27], which serves as the primary industry guideline supporting ISO 14083 [3] implementation and provides practical methodology for calculating and reporting logistics emissions across all transport modes.

1.6 Summary of key concepts / key approaches

Activity	A broad category that can encompass both processes and actions over time, like transporting goods via road transport (e.g., a vehicle driving a distance).
Activity Data	The quantitative measure of the size of a particular process, action or other activity that is a driver of air pollutant emissions (e.g., number of km driven by a vehicle).
Actual Distance	The actual distance travelled by a shipment based on odometer readings or knowledge of the actual route.
Actual Distance with DAF	If SFD or GCD are unavailable, actual distance (e.g., odometer readings or known routes) may be used with a Distance Adjustment Factor (DAF), applying the DAF ensures compatibility between emission intensities calculated from actual distances and transport activity reported using SFD. Mode specific DAFs are available in the GLEC Framework Chapter 3, module 2, and are already embedded in the default emission intensity values on that module.
Consignment	Refers to a quantifiable quantity of cargo that can be distinctly identified as a single unit. It is transported from a sender or consignor to a receiver or consignee, irrespective of the mode of transportation employed.
Distance Adjustment Factor (DAF)	The DAF is the factor expressing the difference between the actual distance and the transport activity distance, which shall be either the SFD or the GCD. It is introduced to ensure that where different types of distance are used at different stages of an emission calculation the resulting calculation errors can be eliminated or minimised. Mode specific DAFs are available in the GLEC Framework Chapter 3, module 2, and are already embedded in the default emission intensity values on that module.
Emission Factor	An emission factor (EF) represents the amount of a certain pollutant emitted to the atmosphere per unit of activity. These research-based values are specific to the details of the activity in question and are routinely published by independent bodies such as in the EMEP/EEA guidebook.
Empty Running	Empty running/an empty trip refers to a transportation operation in which no cargo is being conveyed. It's important to note that the transportation of empty containers, pallets, or other load carriers is not considered an empty trip. In these instances, the load carriers assume the role of the carried freight or transported commodity.
Energy	Electricity, fuels, steam, heat, compressed air and other similar mediums.
Energy Intensity	This is a measure of the energy content used per unit of activity; this would usefully be presented as megajoules per tonne-km (MJ/tkm).
Fuel	The term fuel in this guidance refers exclusively to combustible transport fuels. Electricity is excluded, as it is not a combustible fuel. Fuel data are most accurately reported by mass (kg), although common liquid fuels are frequently quantified by volume for convenience. **Density values for conversion can be found in the GLEC Framework, chapter 3, module 1 in the emission factor tables.**
Fuel Consumption	This is a value for the amount of fuel burned during a period of operation (arbitrary), and is expressed as mass or volume of fuel in kg, tonnes, litres etc.
Fuel Intensity	This is a measure of the amount of fuel burned *per unit* of operation (specific), and is usefully expressed in mass or volume of fuel burned per km or tkm travelled
Great Circle Distance (GCD)	GCD or "as the crow flies," is the shortest path between two points on the Earth's surface, accounting for curvature. Primarily used in air transport, it offers a potential harmonised measure across supply chains but is not yet widely adopted beyond aviation.
Load Factor (LF)	The percentage of a vehicles load capacity which is utilised by a company's freight transport.
Load transported	The mass of freight transported in a vehicle that an individual company is responsible for having shipped (tonnes).
Primary Data	Otherwise known as actual or measured data; it is the "quantified value of a process or an activity from a direct measurement or a calculation based on direct measurements." (source: ISO 14083:2023)
Secondary Data	Any data that is not primary data.
Shortest Feasible Distance (SFD)	The shortest practical route between two places, accounting for real operating conditions such as vehicle restrictions (e.g., weight, height), road type, topography, and congestion. It is

	usually determined using route planning software and is the recommended approach. SFD excludes unrealistic shortcuts that are unsuitable for vehicles or affected by typical urban congestion.
Tier	The Tier represents the level of methodological complexity, and the different Tiers are linked to different types of activity data, and the 'granularity' of data – the level of specificity the data has for e.g., engine type, country, different technologies etc. The selection of one of the three Tiers to use in an emissions inventory is based on data availability: The Tier 1 method is broadly the simplest method and the least data intensive. However, this method comes with substantial uncertainty (elaborated further in a later section), as it represents the most averaged process and activity conditions. Tier 2 is more demanding in terms of the activity data and uses specific information and/or process conditions. Tier 3 uses very detailed country-, user-, vehicle-, process-specific data and is outside of the scope of this guidance Detailed information about the different Tiers and their uses will be given in Section 2.
Tonne-Kilometre (tkm)	The tonne-kilometre (tkm) is a standard metric for the amount of freight transport conducted. As a product of the distance a shipment travelled (km) multiplied by the mass of the freight a company is responsible for (tonnes), this value accounts for both the mass transported and the distance travelled. The user can calculate transport activity according to the following Equation 1. **Equation 1** $tkm = D\ (km) \times LT$ *Where:* *tkm = activity variable for rail in tonnes-km* *D = Distance a vehicle has travelled in km* *LT = Average load transported in tonnes*
Tonne	Metric unit of mass equal to 1000 kilograms.
Transport Activity	Transport activity is the quantification of freight or cargo moved by transport; it is usually expressed in tkm (tonne-kilometres), it characterises the mass (tonnes) transported over a certain distance (km).
Vehicle Load Capacity	The regulated maximum capacity of a vehicle, the maximum freight mass a vehicle is allowed to transport (tonnes).

2

Methods

2. Methodological Approach

2.1 Value chain mapping

To develop the emission inventory, the steps below (Figure 4) outline a process by which a company can identify the sources that emit pollutants across the value chain. For each source, air pollutant emissions will use methods specific to a particular source (e.g., road transport). These steps are consistent with those commonly undertaken to quantify GHG emissions, and the quantification of air pollutant emissions in this guidance is closely aligned with existing frameworks (e.g., GLEC/ISO14083 and the GHG protocol and/or the IPCC methodologies). Therefore, if the company is integrating air pollutant emissions to an existing GHG inventory, existing value chain mapping can be used.

Figure 4 Steps for development of Air pollution emissions inventory [Source: Climate and Clean Air Coalition and Stockholm Environment Institute, 2025]

The first step of estimating air pollution is for companies to develop a comprehensive value chain map. Figure 5 shows the simplified diagram of different activities arising in a company's value chain:

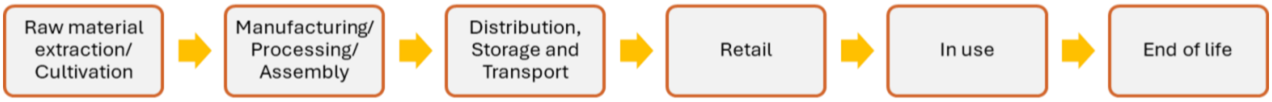


Figure 5 Simplified diagram of company's value chain [Source: Climate and Clean Air Coalition and Stockholm Environment Institute, 2025]

The primary objective of this mapping is to identify specific key emitting sources within the different stages of the value chain (own operations, upstream and downstream).

Air pollutants can be emitted from different sources across a company's value chain (e.g., materials sourcing, production and distribution etc.). Regardless of where the source is within a company's value chain, the same methods can be applied whether the source is part of the company's own operations (also known as Scope 1 emissions), or part of their broader value chain, upstream or downstream (also known as Scope 3 emissions). Simply put, whether a user is wanting to calculate air pollutant emissions that occur from transport from their own operations, or transport occurring elsewhere in their value chain, the same methods will be used.

For this reason, activity data from different parts of the value chain (e.g., total amount of fuel consumed by heavy-duty vehicles from own operations and total amount of fuel consumed by heavy-duty vehicles from upstream/downstream operations) can be aggregated, as long as they remain disaggregated by key emitting source (i.e., road, non-road, rail etc.).

Table 1 provides an overview of the key emitting sources in the corporate value chain and their corresponding allocation to direct (Scope 1), purchased energy (Scope 2), and indirect (Scope 3) emissions.

Table 1 Key emitting sources in the corporate value chain and their allocation across GHG Protocol scopes (1–3)

Key emitting sources	Emission Sources in Corporate Value Chain	Scope 1	Scope 2	Scope 3
Road Transport	Company owned vehicles and hired freight forwarders			
Non-road mobile machinery	Company owned or hired vehicles and agricultural, construction and other non-road vehicles			
Rail Transport	Rail transport: only diesel and locomotive. (Electric rail not in scope of this guidance)			
Shipping	Company owned and hired			
Aviation	Company owned and hired			

2.2 Method selection

The European Monitoring and Evaluation Programme/European Environment Agency (EMEP/EEA) "*National air pollutant emission inventory guidebook*" [12] provides guidance that allows for the development of air pollutant emission inventories at the national level. These methods overlap substantially with those in the Intergovernmental Panel on Climate Change (IPCC) 2006 emission inventory guidelines and where appropriate, the IPCC 2019 Refinement to the 2006 guidelines [28,29]. While the IPCC 2006 and 2019 guidelines provide the appropriate methods for the quantification of GHG emissions, they also recommend that for other pollutants, the EMEP/EEA guidebook [30] is used.

Both the IPCC (2006; 2019) and EMEP/EEA guidebook (2023) use three Tiers to estimate GHG and air pollutant emissions accordingly.

A Tier 1 method is a simple method relying on activity data and default emission factors, this method usually comes with a significant level of uncertainty. Tier 2 and Tier 3 are more demanding in terms of activity data required and emission factors, but they are generally considered to be more accurate with less uncertainty related to them.

The Tier 1 method broadly uses activity data and emission factors and multiplies the **activity data** by appropriate **emission factors** to estimate respective emissions (Equation 2):

Equation 2 Emissions = Activity data x Emission Factors

Where,
Activity data = As an example: Amount of fuel consumed, or kilometres travelled
Emission Factors = Emissions per unit of activity

The activity data variable quantifies how big a particular sector or process is (e.g., the number of terajoules of fuel consumed). Emission factors quantify the mass of pollutant emitted per unit of activity (e.g., the kilograms of black carbon emitted per kilogram of fuel consumed). The default Tier 1 emission factors represent the 'typical' or 'averaged' process conditions and in this document the default EFs are predominantly taken from the EMEP/EEA guidebook. In addition, for some sources, emission factors were taken from the scientific literature and are included in the Appendix I for each pollutant for each source.

The Tier 2 method uses a similar approach to the Tier 1 method, with activity data used but it applies country-specific and/or process- and/or technology-specific emission factors that are developed using specific information on process conditions, fuel quality, abatement technologies, year the technology was developed, and other specificities of the processes it is attempting to quantify the emissions of. The general equation that will be followed for most Tier 2 estimates is Equation 3:

Equation 3 $$Emission_{pollutant} = \sum_{tech}\left(AR_{production,tech} \times EF_{tech,pollutant}\right)$$

The variable '$AR_{production,tech}$' is the production rate of the specific activity within the source category, using a specific technology, and the variable '$EF_{tech,pollutant}$' is the emission factor for the specific technology and pollutant. In some cases, this equation will be diversified to reflect the specificities of the sector and/or technology it is attempting to quantify.

The Tier 3 method uses much more specific information and provides the highest level of granularity out of the three. It usually uses facility specific data, and more advanced calculations. It can account for abatement, different technologies or lines of production within the same facility etc. Tier 3 methods and emission factors are not covered under this guidance, but the user can seek further guidance on those in the EMEP/EEA guidebook (2023) [12].

As discussed in Section 1, air pollutant and GHG emissions share sources and as described above, there is substantial overall alignment between the methods used by the IPCC to quantify GHG emissions and those used by the EMEP/EEA guidebook to quantify air pollutant emissions. While methods to quantify air pollutant and GHG emissions are very closely aligned, there are some nuances between the different frameworks and guidance provided to estimate the quantification of air pollutant and GHG emissions.

Choosing which tier method to use will be based primarily on the type of activity data available and its level of disaggregation The availability of activity data may not be the same for all modes of transport and/or even when the activity data is available, they may not be available at the right level of detail (e.g., total distance travelled is available, but not by vehicle, fuel, and abatement type). Because of this, the user is required to choose whether to use Tier 1or Tier 2 to estimate emissions.

It is best practice for the user to make this decision based on a thorough understanding of the activity data availability, assumptions and quality, but also the equations and the emission factors. The user is expected to choose the method that is the most appropriate for the activity data available, and as this will be for the most part company-specific it is up to the user to ensure that this choice has been made correctly, to avoid unnecessary over- or under-estimates.

The following sections summarise key equations, activity data, and other variables (e.g., fuel intensity) that are needed for the user to complete their calculations and estimate air pollutant emissions. The user is strongly encouraged to refer to the CCAC/SEI Integrated Guide for Businesses for the full context, caveats and assumptions that go with each method and each mode of transport.

2.3 Consistency with GLEC principles

The GLEC Framework provides methodological support both for calculating transport activity (km or tkm), fuel consumption (kg or l), and for applying fuel intensity values (kg of fuel/tkm) across different transport modes. Section 3 Module 2 of the GLEC Framework outlines the relevant parameters, assumptions, and data sources, and should be used as the primary reference to ensure methodological consistency, transparency, and comparability in emissions estimation.

Primary vs. Secondary data

Primary data refers to quantified values obtained directly from measurements or calculations based on a direct measurement. High-quality primary data should be used by transport logistics operators and buyers to calculate emissions. Examples range from precise inputs (e.g., fuel receipts or annual energy bills) to more aggregated values representing energy use or emission intensity across vehicle operations. Secondary data includes all non-primary data, typically categorized as modelled or default data.

- **Primary Data**
  Primary data refers to a company-specific value of a process or activity obtained through direct measurement or data collection (International Organization for Standardization, 2023). Examples include transport activity data, such as the actual distance travelled by a company's vehicles or the tonne-kilometres transported. Primary data could also include the fuel consumed per vehicle. Identifying and collecting the appropriate data is a key step as this will then allow the user to decide on which method (which Tier) will be appropriate to apply to quantify the emissions from the different sources. There may still be occasions where some default data is used to align primary data to GLEC principles. An example is collecting loaded distance travelled but applying empty running default data to ensure it reflects the total distance.
  A company/user may not have access to all the data required to put together a complete inventory. There are several reasons why a company and/or user may not have access to data with a higher level of detail that could be used to apply a Tier 2 (or Tier 3) method. These reasons include commercial sensitivity of the data, lack of direct measurements, high cost of the data that needs to be obtained. If primary data is available, the user should directly apply the calculation methods presented in this methodology, selecting the appropriate tier. It is important to ensure that primary data is at the level of granularity required to use the appropriate tier methods, this is discussed further in the respective section for each mode.
- **Secondary Data**
  When primary data is not available, users should use secondary data [3], that can be classified as modelled data and default data.
  Modelled data refers to information modelled from primary data and/or Air Pollutants-relevant parameters of transport or hub operations. Companies and tool providers estimate energy use and emissions using factors such as goods type, consignment size, origin, destination, handling points, vehicle details, and load factors. The accuracy of results depends on data detail, assumptions, and the model's algorithms.
  To align with the GLEC Framework, modelling methods must ensure transparency, consistency, and comparability in emissions accounting. This requires clearly defining boundaries and scopes, applying Transport Operation Categories (TOCs) correctly, calculating distances in accordance with GLEC guidance, and systematically including empty running to avoid underestimating emissions. Primary data should be prioritised over defaults, and robust, recognised emission factors must be applied consistently. Exclusions such as irregular detours (e.g., weather, congestion) should be avoided to maintain methodological integrity. Finally, results must be reported in standardised units with full documentation of primary data and default value sources, assumptions, and calculation methods to enable verification.
  Default data reflects average industry practices and should be used only as a last resort in accounting reports. It is most useful for organisations at the early stages of emissions reporting, as it can provide a general indication of emissions, highlight hotspots, and support establish a framework for prioritising further data collection to improve accuracy. The source of any default data used must be clearly specified.

Guidance on appropriate use

Primary data should always be used where company-specific and verifiable data are available, as it enables the most accurate quantification of emissions and supports robust performance tracking. Primary data needs to be disaggregated appropriately to satisfy the requirements of the emission factors. If it is not available at this level of detail a different Tier method or different data types may be required.

Modelled data should be applied where direct measurements are not feasible but sufficient operational detail exists to generate reasonable estimates, ensuring that the modelling methods follow recognised frameworks such as the GLEC. Default data should only be relied upon when neither primary nor modelled data is available, and its use should be supported by a clear acknowledgment of the associated uncertainty.

Handling of incomplete data

In some instances, datasets may be incomplete or include missing data. It is suggested that primary data is used in the first instance and calculations from modelled or default data is used to bring the dataset in line with the requirements for the Tier method. If additional assumptions or use of default or modelled data is required, it is important to carefully note and document these assumptions, aiming at improving the data quality in future calculations. If it is not possible for the user to obtain the necessary activity data (primary, or secondary) then it is best practice to note which modes of transport, and which calculations are impacted by the lack of data and for this to be clearly stated as part of the limitations of the quantification of air pollutants and/or the inventory.

Uncertainties

Depending on the type of primary, or secondary data the user will have available, and the choice of Tier 1 or Tier 2 emission factors, a higher or lower level of uncertainty may exist. It is good practice for the user to calculate the uncertainty, and while it is beyond the scope of this guidance to provide the full methods for the quantification of uncertainties, the user can refer to the CCAC/SEI Integrated Guide for Business, Chapter 4 (Uncertainties).

2.4 GLEC considerations

This paragraph outlines the key concepts from the GLEC Framework that support the emissions calculation methodology presented in this document, including the underlying assumptions related to transport activity and fuel data. In all instances, the use of transport activity data should follow the GLEC framework methods and principles. For more details please consult the GLEC Framework.

Transport activity

Generally, the freight transport activity is calculated by multiplying the mass of each consignment with its specific transport activity distance (Figure 6). It is expressed in tonne-kilometres (or tonne-km or tkm), where **freight mass** is quantified in metric tons. **Distance** is quantified in km and shall be the Shortest Feasible Distance (SFD) or the Great Circle Distance (GCD). When actual distance is used, the use of a mode specific Distance Adjustment Factor (DAF) is necessary, and documented in Section 3, Module 2 of the GLEC Framework. The resulting value is expressed in tonne-kilometres. One tonne-kilometre represents one tonne of cargo moving for one kilometre.

Figure 6 Transport activity calculation for a transport chain element (TCE). Adapted from GLEC Framework V3.1, for more details please consult the GLEC Framework

Load Transported and Load Factor

The quantity of freight to be considered, shall only include the mass of the packaging that was initially provided by the shipper (or the organisation that sent the consignment), without including additional specific transport packaging or containers.

When estimating emissions, this is a fundamental aspect to be considered. Therefore, it is also important to only estimate emissions based on the share of weight that is relevant for the user. To support this, it is useful to think of transport activity as the allocation parameter. By identifying the related transport share, emissions can be associated with only the relevant shipment mass. If the total load is not known, the best available estimates or assumptions based on vehicle capacity and utilisation can be applied. The GLEC Framework provides mode-specific industry average load factors (in percentage of total carried weights over maximum payload capacity) in Section 3, module 2.

Empty running

The GLEC Framework recommends a round-trip approach in emissions calculations. This means that empty trips/sections of routes in which no freight is transported, shall be included when quantifying emissions. This includes for example vehicle repositioning trips, or empty backhauls. In the case of available primary fuel consumption data, but no available information on empty running, the GLEC defaults suggest an industry average that is mode specific and is available in Section 3, Module 2. This percentage refers to a total distance and must be adjusted accordingly where only loaded distance is known. For instance, the GLEC Framework takes an average 17% empty running value for road freight transport. This value is based on the total distance and should be adjusted when only the loaded distance is known. This reflects in a 20.48% uplift to be applied to the loaded distance.

Fuel intensity

Important: If the user has primary fuel consumption (FC), this value can be directly used in the formula and multiplied with the emission factor, without the need to multiply fuel intensity and transport activity (since fuel consumption FC= tkm x FI).

Fuel intensity is defined as the quantity of fuel burned per unit of transport activity (kg/tkm). If this cannot be estimated from primary fuel consumption data, default fuel intensity values are provided in the GLEC Framework (Section 3, Module 2) for the relevant transport modes. Where this value is not available, it can be estimated with the following Equation

Equation 4 $FI = \frac{EI}{fuel\ EF}$

Where:
FI = Fuel Intensity (kg fuel/tkm)
EI = Emission intensity value (kgCO2e/tkm)
Fuel EF = Fuel emission factor (kgCO2e/kg fuel)

Note: if the units differ from the ones expressed in the equation above, adjustments have to be made. It is important to ensure **consistency** with the choice of emission intensity and fuel emission factors (TTW or WTW), as mixing inconsistent values will result in incorrect outcomes.

GLEC limitations

While the GLEC Framework provides a globally recognised methodology for harmonized emissions accounting in freight transport, it has several important limitations that should be acknowledged:

- Vehicle and Technology Abatement - The framework does not capture the impact of specific vehicle-level improvements such as aerodynamic retrofits, tyre technology, alternative drivetrains, or other abatement measures. Users relying solely on GLEC defaults may therefore overlook efficiency gains already implemented in their fleets.

- Engine Technology and Euro Standards - GLEC does not differentiate between vehicles by Euro emission standard or equivalent engine technologies. As a result, the framework cannot reflect the variation in pollutant emissions arising from different vehicle generations. Where primary data on vehicle type or Euro class is not available, only Tier 1 (default) methods can be applied, which increases uncertainty.
- Non-Road Transport Data Gaps – GLEC does not provide methodological guidance or default values for non-road transport modes, such as vehicles and equipment used in agriculture, forestry, and industry.
- Because of these limitations, reliance on default or secondary data should be considered only a starting point. Organizations are encouraged to progressively improve data quality by gathering primary operational data (fuel consumption, load factors, vehicle specifications) to reduce uncertainty and ensure results reflect actual performance.

2.5 Methods to calculate air pollutant emissions

In this section we will discuss and present the sources, methods, activity data and emission factors following the principles established in the EMEP/EEA guidebook, the Black Carbon Methodology for the Logistics Sector (2017) [31], the GLEC Framework: Global Logistics Emissions Council Framework [27] and the Climate and Clean Air Coalition (CCAC) and Stockholm Environment Institute (SEI) methodologies: A Practical Guide for Business Air Pollutant Emission Assessment (2022) and CCAC/SEI Integrated Guide for Business GHG and Air Pollutant Emission Assessment [10] .

The air pollutants emitted from the fuel combustion in different modes of transport across a company's value chain that this guidance is focusing on are PM_{10}, $PM_{2.5}$, SO_x, NO_x, CO, and BC. For a full list of air pollutant emissions from transport the user can refer to the EMEP/EEA guidebook (2023)[12].

To estimate emissions from transport and activities such as the combustion of fuel, the user will typically need to multiply activity data by an appropriate emission factor (EF), such as fuel consumed (e.g., g of pollutant per kg of fuel) or distance travelled (g of pollutant per km travelled)[30].

Depending on the mode of transport for which we are quantifying emissions, the activity data can be broadly either the total amount of fuel consumed by a specific type of vehicle and/or vessel, or the distance travelled.

Choice of methods

While it is always best practice for the inventory compiler to choose the method with the highest level of accuracy (e.g., Tier 2 or Tier 3), it may also not be possible for that specific method to be chosen to the lack of a) data, or b) data disaggregated at the appropriate level of detail. For example, the quantification of air pollutant emissions for certain modes of transport for the Tier 2 methods may require additional information beyond fuel use or distance travelled, particularly details about the vehicle type, age, and/or abatement used.

Specific details will be given under the methods described for each mode of transport for the requirements of the Tier 1 and Tier 2 methodologies. This distinction in the type and level of disaggregation of activity data should be considered when developing an air pollutant emissions inventory and will be further highlighted in the following sections.

2.5.1 Road Transport

Quantifying air pollutant emissions from road transport, i.e., emissions from heavy duty vehicles (HDVs) and light commercial vehicles (LCVs), can be done by using primary activity data (which is company specific activity data, e.g., total amount of fuel consumed by a vehicle type) if available.

For road transport, no default activity data are available. There are two Tiers available that can be chosen based on the level of information available to the user.
The Tier 1 method requires primary activity data specific to the total amount of different fuels consumed by the vehicles, disaggregated by vehicle type,

The Tier 2 method requires information on the distance travelled (km) disaggregated by vehicle type (including weight), type of fuel used, and vehicle emission standard (e.g., euro standard) *or* if the information on vehicle emission standard is not available, the age of the vehicle, which can be correlated to a standard according to Table S1 reproduced from the EMEP/EEA guidebook. Table 2 summarizes the equations and input data required to estimate road transport air pollutant emissions under Tier 1 and Tier 2 approaches.

The EMEP/EEA guidebook contains published emission factors for road transport:

- **Tier 1** emission factors are expressed in grams of pollutant per kilogram of fuel consumed (g/kg of fuel),
- **Tier 2** emission factors are expressed in grams per vehicle-km travelled (g/km).

Table 2 Summary of data inputs for Tier 1 and Tier 2 approaches

	TIER 1	TIER 2
Overview	Choose the Tier method based on: • Type of activity data available and any required assumptions • Activity data disaggregated at the appropriate level of detail for the Tier methods' emission factors	
	This method should be chosen if the user has primary activity data of the total amount of fuel that is consumed (kg), disaggregated by fuel type and vehicle category (e.g., how much *diesel* was consumed by *heavy-duty* vehicles). An alternative equation provides a method for converting tkm to kg of fuel.	This method should be chosen if the user has information regarding total distance travelled disaggregated by vehicle category and abatement (for example, how much distance was travelled by the heavy-duty vehicles, with Euro 4 engine). An alternative equation provides a method for converting tkm to km travelled, which can be used if tkm is available disaggregated for Tier 2.
Equations (a)	**Equation 5** $Em_{k,v,f} = FC_{v,\mathrm{f}} \times EF_{k,v,\mathrm{f}}$	**Equation 6** $Em_{k,v,f,s} = km_{v,f,s} \times EF_{k,v,\mathrm{f,s}}$

	TIER 1	TIER 2
Data required See following table for more details	*Where,* ***$Em_{k,v,,f}$*** *= emissions of the specific pollutant k for vehicle type v, and fuel f (g)* ***$FC_{v,f}$*** *= fuel consumption by vehicle type v using fuel f (kg)* ***$EF_{k,v,f}$*** *= emission factor for pollutant k, vehicle type v, and fuel f (g/kg of fuel consumed)*	*Where,* ***$EM_{k,v,f,s}$*** *= Emissions of pollutant k by vehicle type v, fuel f, and emissions standard s (g)* ***$km_{v,f,s}$*** *= Distance travelled using vehicle type v, fuel f, and emission standard s (km)* ***$EF_{k,v,f,s}$*** *= Emission factors specific to vehicle type v, fuel f, and emissions standard s (g/vehicle-km)*
Alternative Equations (b)	**Equation 7** $$Em_{k,f} = tkm_{v,f} \times FI_{v,f} \times EF_{k,f}$$	**Equation 8** $$Em_{k,v,f,s} = \frac{tkm_{v,f,s}}{LT_{v,f,s}} \times EF_{k,v,\mathrm{f},\mathrm{s}}$$
Data required See following table for more details	*Where,* ***$Em_{k,v,,f}$*** *= emissions of the specific pollutant k for vehicle type v, and fuel f (g)* ***tkm_f*** *= Tonne-km travelled using vehicle type v powered by fuel f (tkm)* ***$FI_{v,f}$*** *= Fuel intensity for vehicle type v, and fuel f (kg-fuel/tkm)* ***$EF_{k,v,f}$*** *= emission factor for pollutant k, vehicle type v, and fuel f (g/kg of fuel combusted)*	*Where,* ***$Em_{k,v,f,s}$*** *= Emissions of pollutant k by vehicle type v, fuel f, and emissions standard s (g)* ***$tkm_{v,f,s}$*** *= tonnes-kilometres travelled using vehicle type v, fuel f, and emission standard s (tkm)* ***$LT_{v,f,s}$*** *= Average load transported by vehicle v, fuel f, and emission standard s (tonnes)* ***$EF_{k,v,f,s}$*** *= Emission factors specific to vehicle type v, fuel f, and emissions standard s (g/vehicle-km)*
Disaggregation	Activity data (total fuel consumed) must be disaggregated by vehicle and fuel type (e.g., Total amount of diesel consumed by heavy duty vehicles).	Activity data (distance travelled and/or tkm transported) must be disaggregated by vehicle type (including weight), emissions standard and fuel type (e.g., total amount of diesel consumed by a Euro 6 heavy duty vehicle (16 t)).

	TIER 1	TIER 2
Notes	If the user has activity data in km or tkm, then the methodology for Tier 2 should be considered. In the case where activity data in km is available without disaggregation to specify type of abatement or euro standard, the km travelled can be converted to kg for use in the Tier 1 methodology using average fuel economy. Using diesel blended with various proportions of biofuels can significantly influence emission levels compared to using pure diesel. An additional step can be taken for companies using biofuels to revise the emission factor. This is described at the end of this section.	

Data required

To ensure consistency with the GLEC Framework, Table 3 summarises the core data inputs required for emission calculations, their units, sources of availability, and the aligned data assumptions that must be applied.

Table 3 Data Requirements and GLEC-Aligned Assumptions for Emission Calculations

Data	Units	Data availability	GLEC aligned – data assumptions
Fuel Consumption (FC) *Tier 1 only*	kg	This parameter is usually collected by the user or provided by a supplier. If the data for fuel consumption is in litres or another unit, it must be converted. The GLEC Framework Section 3, Module 1 have some standard density factors which can be used.	In case primary fuel consumption is only available/known for the loaded trip, an adjustment for empty running should be included by adding the proportion of fuel corresponding to empty trips, based on the percentage of empty running relative to total operations. Default empty running values are provided in Section 3, Module 2 of the GLEC Framework, within the table of European rail diesel traction emission intensity values.
Emission factor (EF)	g/kg or g/vehicle km	See below for EFs for Tier 1, further emission factors for Tier 2 (expressed in gram of pollutant per kilometre travelled (g/km) can be found in Appendix I.	N/A
Distance travelled *Tier 2 only*	km	Distance travelled is usually calculated or provided to the user by a supplier. In some cases, the user may only have been provided tkm, which can be	Distance must always be calculated in accordance with the GLEC Framework. Values for the SFD based on the road network can usually be sourced from route planning software or maps.

Data	Units	Data availability	GLEC aligned – data assumptions
		converted to km using the data assumptions outlined in the cell below. *Note this is required for the Tier 2 method only.*	To calculate emissions, distance travelled should always be the total distance (loaded distance + empty running). Default values provided in the GLEC Framework Section 3, Module 2 may be applied where necessary, with further clarification available in this guidance section 2.1.
Transport activity *Tier 1 alternative or conversion to km in Tier 2*	tkm (tonne-km)	Convert from tkm to km by using GLEC Framework Section 1, Chapter 4. Transport activity (tkm) is usually calculated or provided to the user by a supplier. Sometimes in the form of simply distance (km) and shipment mass (or load transported) (tonnes). *tkm = distance (km) × mass (tonnes).*	Distance must be calculated as outlined above. Note that transport activity distance is usually the **loaded distance**, therefore **empty running must be included**.
Load transported (LT) *Used for conversion to km in the Tier 2 alternative*	tonnes	Use LT to help convert tkm to km (for use in the alternative equation). More information can be found in GLEC Framework Section 1, Chapter 4. Load Transported is usually collected by the user or provided by a supplier.	**For Load Transported (LT), actual mass in tonnes** is to be used. If this is not available, estimated weight based on the mass of the cargo can be applied. Default values provided in the GLEC Framework Section 3, Module 2 may be applied where necessary.
Fuel intensity (FI) *Tier 1 alternative*	kg fuel / tkm	Primary fuel consumption (kg fuel) can be used and divided by the transport activity (tkm) to obtain the FI value. Default reference FI values are available in the GLEC Framework (Chapter 3, Module 2).	See considerations for fuel consumption and tonne-km above.

Emission factors

Default emission factors for Tier 1 road transport air pollutants are shown in Table 4 [12]. Emission factors for the Tier 2 method can be found in Appendix I.

Table 4 Tier 1 emission factors for road air pollutants

Cat	Fuel	Pollutant-Specific Emission Factor (g/kg-fuel)					
		CO	NO_x	PM_{10}	$PM_{2.5}$[a]	BC[b]	N_2O
LCV	Petrol	118.7	5.93	0.02	0.02	0.001	0.1
	Diesel	6.81	13.48	1.22	1.22	0.671	0.07
HDV	Diesel	6.1	25.95	0.55	0.55	0.2915	0.07
	CNG (Buses)	3.98	17.1	0.02	0.02	-	0.27

Biofuel use in Road Transport

Companies often use diesel blended with various proportions of biofuels, which can significantly influence emission levels compared to using pure diesel. According to the EMEP/EEA (2023) guidebook [12], emission factors vary based on the blend ratio of biofuel to diesel. These guidelines provide percentage reductions in emissions for standard blends such as B0 (100% diesel), B10, B20, and B100 (100% biofuel), as shown in Table 5.

The EMEP/EEA guidebook presents the percentage change in diesel vehicle emissions when using different mixes of biodiesel compared to fossil fuel diesel (reproduced in Table 5).

Table 5 Effect of biodiesel on diesel vehicle emissions, adapted from the EMEP/EEA guidebook 2023.

Pollutant	Vehicle Type	B10	B20	B100
NO_X	Passenger Cars	0.4 %	1.0 %	9.0%
	Light Commercial Vehicles	1.7 %	2.0 %	
	Heavy-duty vehicles	3.0 %	3.5 %	
PM	Passenger Cars	-13.0 %	-20.0 %	-47.0 %
	Light Commercial Vehicles	-15.0 %	-20.0 %	
	Heavy-duty vehicles	-10.0 %	-15.0 %	

Based on these percentage changes, Equation 9 defines the revised emission factor. This adjusted factor can be multiplied by an activity data according to Equations 5-8.

Equation 9 $$RevEF_{k,v,f} = \sum_c \left(EF_{k,v,f} \left(1 - \frac{Cc}{100}\right)\right)$$

Where,

$RevEF_{k,f,e}$= revised biodiesel mix-specific emission factor of pollutant k, fuel type f (g/kg) and vehicle type v

$EF_{k,v,f}$ = fuel biodiesel mix-specific emission factor of pollutant k, fuel type f (g/kg) and vehicle type v

C_c = correction factor for biofuel

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[a] The EF of *both, PM_{10} and $PM_{2.5}$ have the same value because in this instance all PM is $PM_{2.5}$. Therefore, PM = PM 10 = PM 2.5*

[b]Black Carbon is 0.05 of PM of LCV petrol and 0.55 of PM LCV diesel.
Black Carbon is 0.53 of PM of HDV diesel.

These can be applied to the Tier 1 or the Tier 2 method provided the level of disaggregation is accurate. Please note that the Equation 9 will give a revised EF for estimating emissions from biofuel.

Determining SO_X emissions from Road

The emissions of SO_2 per fuel type *f* are estimated by assuming that all sulphur in the fuel is transformed completely into SO_2 using Equation 10.

Equation 10 $Em_{SO2,f} = 2 \times k_{S,f} \times FC_f$

Where,

$Em_{SO2,f}$ = *Emissions of SO_2 by burning activity of fuel f (g)*

$k_{S,f}$ = *Weight-related sulphur content in fuel f (g/g)*

FC_f = *Mass of fuel consumed for fuel f (g)*

Values for the typical sulphur content of petrol and diesel are reproduced from the EMEP/EEA guidebook in Table 6. These values in parts per million (ppm) can be converted to grams of sulphur per gram of fuel (g/g) as required in Equation 10 by dividing by 10^6.

Table 6 Typical sulphur content of fuels (Reproduced from Tier 1 Road, EMEP/EEA guidebook)

Fuel	Sulphur Content (ppm)			
	1996 Base fuel (Market Average)	Fuel 2000	Fuel 2005	Fuel 2009 and Later
Petrol	165	130	40	5
Diesel	400	300	40	3

For expanded information, context and example calculations on road transport emissions, the user is encouraged to visit Chapter 3, Section 3.3 in the CCAC/SEI Integrated Guide for Business. For expanded information on the methods and emission factors users are referred to the EMEP/EEA guidebook Chapter 1.A.3.b.i-iv.

2.5.2 Non-Road mobile machinery

According to IPCC (2006; 2019) guidelines, the non-road category includes vehicles and mobile machinery used in agriculture, forestry, industry (including construction and maintenance), residential sectors, and equipment such as agricultural tractors and forklifts.

The types of non-road equipment covered by the EMEP/EEA (2023) guidebook include the following categories, defined by the following EMEP/EEA Nomenclature For Reporting (NFRs):

- 1.A.2.g vii: Mobile combustion in manufacturing industries and construction
- 1.A.4.a.ii: Commercial and institutional mobile machinery
- 1.A.4.b ii: Mobile combustion used in residential areas; household and gardening mobile machinery
- 1.A.4.c ii: Off-road vehicles and other machinery used in agriculture and forestry

The engines used in these categories include diesel engines, four-stroke and two-stroke petrol engines, or liquid petroleum gas (LPG) engines. Both the Tier 1 and Tier 2 emission factors published in the EMEP/EEA guidebook for non-road transport are expressed in grams of pollutant per tonne of fuel consumption (g/tonne of fuel). There are two methods to estimate emissions from non-road mobile machinery. The simplified or Tier 1 method takes account of fuel and engine type, whereas Tier 2 accounts for fuel, engine, and equipment technology (Table 7).

Table 7 Summary of data inputs for Tier 1 and Tier 2 approaches for Non-Road Mobile Machinery

<table>
<tr><th></th><th>TIER 1</th><th>TIER 2</th></tr>
<tr><td>Overview</td><td colspan="2">Choose the Tier method based on:
• Activity data available to the user and any required assumptions
• Activity data disaggregated at the appropriate level of detail for the Tier methods’ emission factors</td></tr>
<tr><td></td><td>This method should be chosen if the user has information regarding the total amount of fuel that is consumed disaggregated by fuel type and NFR category (for example, how much diesel was consumed by agricultural tractors), and data on engine type.</td><td>This method should be chosen if the user has information regarding the total amount of fuel that is consumed disaggregated by fuel type ,NFR category (for example, how much diesel was consumed by the agricultural tractors), and data on engine type and abatement technology.</td></tr>
<tr><td>Equations</td><td>Equation 11
$$Em_{k,c,f,e} = FC_{c,f,e} \times EF_{k,c,f,e}$$</td><td>Equation 12
$$Em_{k,c,f,e,t} = FC_{c,f,e,t} \times EF_{k,c,f,e,t}$$</td></tr>
<tr><td>Data required

See following table for more details</td><td>Where,
$\boldsymbol{Em_{k,c,f,e}}$ = emissions of the specific pollutant k for NFR category c, fuel type f, and engine type e (g)*
$\boldsymbol{FC_{c,f,e}}$ = Fuel consumed per NFR category c, fuel type f, and engine type e (unit of fuel)*
$\boldsymbol{EF_{k,f,s}}$ = emission factor for pollutant k for NFR category c, fuel type f, and engine type e (g/unit of fuel)*</td><td>Where,
$\boldsymbol{Em_{k,c,f,e,y}}$ = emissions of the specific pollutant k (g)*
$\boldsymbol{FC_{c,f,e,y}}$ = Fuel consumed per NFR category c, fuel type f, engine type e, and equipment technology t (tonne of fuel) *
$\boldsymbol{EF_{k,c,f,e,y}}$ = emission factor for pollutant k for NFR category c, fuel type f, engine type e, and equipment technology t (g/tonne of fuel) *</td></tr>
<tr><td>Disaggregation</td><td>Activity data (total amount of fuel consumed) is disaggregated by NFR category, fuel, and engine type. E.g., Gasoline burned by 1.A.4.c.ii-Agriculture machinery with a two-stroke engine.

Note: not every category requires disaggregation by engine type e.g., diesel</td><td>Activity data (total amount of fuel consumed) is disaggregated by NFR category, fuel, engine type, and equipment technology (year of manufacture /Euro standard).
E.g., Gasoline burned by 1.A.4.c.ii-Agriculture machinery with a two-stroke engine with Euro standard II.</td></tr>
</table>

	TIER 1	TIER 2
		Note: not every category requires disaggregation by engine type e.g., diesel
Important Note	**Users are expected to adapt the units of all equations according to the units of the emission factors they use.* *This is particularly important for calculations for non-road mobile machinery since the* ***units of emission factors published in the EMEP/EEA guidebook change according to the pollutant and NFR category they are relevant to.***	

Emission Factors
Default emission factors for Tier 1 and Tier 2 road transport air pollutants are reproduced from the EMEP/EEA guidebook in Appendix I Table S4 and Table S5, respectively.

Data required
To ensure consistency with the GLEC Framework, Table 8 summarises the core data inputs required for emission calculations, their units, sources of availability, and the aligned data assumptions that must be applied.

Table 8 Data Requirements and GLEC-Aligned Assumptions for Emission Calculations

Data	Units	Data availability	GLEC aligned - data assumptions
Fuel Consumption (FC)	kg or tonne	This parameter is usually collected by the user or provided by a supplier. If the data for fuel consumption is in litres or other unit, it must be converted. The GLEC Framework Section 3, Module 1 have some standard density factors which can be used.	The GLEC Framework does not currently include NRMM. This should not prevent users from carrying out calculations. The limitations of GLEC default values in these cases must be acknowledged as mentioned in section 2.4.3. Users are encouraged to apply primary or modelled data where possible to improve accuracy.
Emission factor (EF)	kg / unit-fuel	Default emission factors for Tiers 1 and 2 are reproduced from the EMEP/EEA guidebook (2023), in Appendix I	

For expanded information context and example calculations, the user is encouraged to visit Chapter 3, Section 3.3 in the CCAC/SEI Integrated Guide for Business. For expanded information on the methods and emission factors users are referred to the EMEP/EEA guidebook Chapter 1.A.4

2.5.3 Rail Transport

Both the Tier 1 and Tier 2 emission factors published in the EMEP/EEA guidebook for rail transport are expressed in kilograms (or grams) of pollutant per tonne of fuel consumed which is why the activity variables used for the calculations will need to be expressed in kilogram of fuel (or tonnes). Table 9 summarizes the equations and input data required to estimate rail transport air pollutant emissions under Tier 1 and Tier 2 approaches.

It must be noted that this section accounts for emissions from rail that result from the consumption fuel. The emissions from electric rail can also be estimated from electricity consumption, and users wishing to include emissions from this key emitting source can refer to CCAC-SEI Integrated Guide for Business (2025)[10].

Table 9 Summary of data inputs for Tier 1 and Tier 2 approaches

	TIER 1	TIER 2
Overview	Choose the Tier method based on: • Activity data available to the user and any required assumptions • Activity data disaggregated at the appropriate level of detail for the Tier methods' emission factors	
Equations (a)	**Equation 13** $\boldsymbol{Em_{k,f} = FC_f \times EF_{k,f}}$	**Equation 14** $\boldsymbol{Em_{k,f,j} = FC_{f,j} \times EF_{k,f,j}}$
Data required See following table for more details	*Where,* $\boldsymbol{Em_{k,f}}$ = *Amount of pollutant k emitted by burning of fuel f (kg)* $\boldsymbol{FC_f}$ = *Amount of fuel f consumed (tonnes)* $\boldsymbol{EF_{k,f}}$ = *Emission factor specific to fuel f and pollutant k (kg/tonne)**	*Where,* $\boldsymbol{Em_{k,f,j}}$ = *Amount of pollutant k emitted by burning of fuel f in locomotive j (kg)* $\boldsymbol{FC_{f,j}}$ = *Amount of fuel f consumed by locomotive j (tonnes)* $\boldsymbol{EF_{k,f,j}}$ = *Emission factor specific to fuel f, pollutant k, and locomotive j (kg/tonne)**
Alternative Equations (b)	**Equation 15** $Em_{k,f} = tkm_f \times FI_f \times EF_{k,f}$	**Equation 16** $Em_{k,f,j} = tkm_{fj} \times FI_{f,j} \times EF_{k,f,j}$

	TIER 1	TIER 2
Data required See following table for more details	$\boldsymbol{Em_{k,f}}$ = *Amount of pollutant k emitted by burning of fuel f (kg)* $\boldsymbol{tkm_f}$ = *tonne-km travelled using rail powered by fuel f (tkm)* $\boldsymbol{FI_f}$ = *Fuel intensity for rail using fuel f (tonne-fuel/tkm)*	$\boldsymbol{Em_{k,f,j}}$ = *Amount of pollutant k emitted by burning of fuel f using locomotive type j (kg)* $\boldsymbol{tkm_{f,j}}$ = *tonne-km travelled using locomotive type j by burning fuel f (tkm)* $\boldsymbol{FI_{f,j}}$ = *Fuel intensity for rail using fuel f and locomotive type j (tonne-fuel/tkm)*
Disaggregation	Activity data (total amount of fuel consumed) is disaggregated by fuel. E.g., Rail operated by burning gas oil/diesel.	*Activity data (total amount of fuel consumed) is disaggregated by fuel and locomotive type.* *E.g., Rail operated by burning gas oil/diesel in a shunting locomotive.*
Notes	The fuel-based equations can be applied when the total fuel consumption is known for the users' own operations. In some instances, it may overestimate emissions if the fuel consumption does not distinguish fuel used for the company's own cargo from that used for other freight in the same vehicle. The tkm-based equations replace total fuel consumption with tonne-kilometres transported (tkm), multiplied by fuel intensity (kg fuel per tkm), providing a way of allocating emissions to a portion of the load.	
Important Note	***Users are expected to adapt the units of all equations according to the units of the emission factors they use.* *This is particularly important for calculations for rail since the* ***units of emission factors published in the EMEP/EEA guidebook change according to the pollutant they are relevant to.***	

Data required

To ensure consistency with the GLEC Framework, Table 10 summarizes the core data inputs required for emission calculations, their units, sources of availability, and the aligned data assumptions that must be applied.

Table 10 Data Requirements and GLEC-Aligned Assumptions for Emission Calculations

Data	Units	Data availability	GLEC aligned - data assumptions
Fuel Consumption (FC)	tonnes	This parameter is usually collected by the user, or provided by a supplier.	In case primary fuel consumption is only available/known for the loaded trip, an adjustment for empty running should be included by adding the proportion of fuel

Data	Units	Data availability	GLEC aligned - data assumptions
		If the data for fuel consumption is in litres or other unit, it must be converted. The GLEC Framework Section 3, Module 1 have some standard density factors which can be used.	corresponding to empty trips, based on the percentage of empty running relative to total operations. Default empty running values are provided in Section 3, Module 2 of the GLEC Framework, within the table of European rail diesel traction emission intensity values.
Emission factor (EF)	Kg / tonne fuel	See below for EFs for Tier 1, further emission factors for Tier 2 are in Appendix I.	N/A
Transport activity	tkm (tonne-km)	Transport activity (tkm) is usually calculated or provided to the user by a supplier. Sometimes in the form of simply distance (km) and shipment mass (or load transported) (tonnes). *tkm = distance (km) × mass (tonnes).*	Transport activity must always be calculated in accordance with the GLEC Framework. **Actual mass in tonnes** should be used. If this is not available, apply an estimated weight based on cargo characteristics. Average load factors for default values are not well-established for rail transport. The GLEC Framework suggests average capacity data sources in Section 1, chapter 4 under the topic "Requirements for rail transport calculations". Rail transport activity should preferably be calculated based on the SFD, using the start and end point of the journey, i.e. the **loaded distance.** GHG emission calculation tools offer a rail distance calculator where the information is not available. When using actual distance, a mode-specific DAF must be applied (see GLEC Framework, Section 3, Module 2).
Fuel intensity (FI)	Tonne fuel / tkm	Primary fuel consumption (kg fuel) can be used and divided by the transport activity (tkm) to obtain the FI value. Default reference FI values are available in the GLEC Framework	See considerations for fuel consumption and tonne-km above.

Data	Units	Data availability	GLEC aligned - data assumptions
		(Chapter 3, Module 2), within the table of European rail diesel traction emission intensity values.	

Emission factors

Emission factors are reproduced from the EMEP/EEA guidebook (2023) [10] for the Tier 1 method (Table 11). Emission factors for the Tier 2 method can be found in Appendix I, Table S6.

Table 11 Tier 1 emission factors for rail air pollutants (Gas Oil/Diesel)

PM10	PM2.5	BC (<PM10)*	BC** (<PM2.5)
kg/tonne fuel	kg/tonne fuel	kg/tonne fuel	kg/tonne fuel
1.44	1.37	0.936	0.8905

NB[c]: Black Carbon (BC) is 0.65 of PM

For expanded information, the user is encouraged to visit Chapter 3, Section 3.3 in the CCAC/SEI Integrated Guide for Business. For expanded information on the methods and emission factors users are referred to the EMEP/EEA guidebook Chapter 1.A.3.c.

2.5.4 Shipping

When calculating air pollutant emissions from freight transported by vessels, the activity data (kg-fuel or tonne-km) should be disaggregated by fuel (e.g., diesel, fuel oil, gasoline).

There are two methods to estimate emissions from shipping. Tier 1 approach calculates emissions from vessels based on activity data (such as tonne-kilometres or fuel consumption), whereas the Tier 2 approach accounts for the activity data by *different types* of vessels with different types of engines (Table 12).

This section covers both **sea** and **inland waterways**. It does not distinguish between the two, users should ensure that the correct default values are applied where primary data are not available.

In shipping, an additional step is needed to quantify air pollutants, which is emission control technologies. More information is available below under "Shipping and Emission Controls."

[c]Since black carbon is necessarily part of particulate matter, the emission factors for BC are often given as a fraction or ratio of the listed PM. As such, when listing the emission factors for BC it can be categorised as two different sizes of BC (less than 10 micrometers/less than 2.5 micrometers).

Table 12 Summary of data inputs for Tier 1 and Tier 2 approaches

	TIER 1	TIER 2
Overview	Choose the Tier method based on: • The activity data available to the user and any required assumptions • Activity data disaggregated at the appropriate level of detail for the Tier methods' emission factors	
Equations	**Equation 17** $Em_{k,f} = FC_f \times EF_{k,f}$	**Equation 18** $Em_{k,f,j} = FC_{f,j} \times EF_{k,f,j}$
Data required See following table for more details	*Where,* $\boldsymbol{Em_{k,f}}$ *= Amount of pollutant k emitted by burning of fuel f (kg)** $\boldsymbol{FC_f}$ *= Amount of fuel f consumption (tonnes)* $\boldsymbol{EF_{k,f}}$ *= Emission factor specific to fuel f and pollutant k (kg/tonne)**	*Where,* $\boldsymbol{Em_{k,f,j}}$ *= Amount of pollutant k emitted by burning of fuel f in vessel j (kg)* $\boldsymbol{FC_{f,j}}$ *= Amount of fuel consumed by vessel j (tonnes)* $\boldsymbol{EF_{k,f,j}}$ *= Emission factor specific to fuel f, pollutant k, and vessel j (kg/tonne)*
Alternative Equations (b)	**Equation 19** $Em_{k,f} = tkm_f \times FI_f \times EF_{k,f}$	**Equation 20** $Em_{k,f,j} = tkm_{fj} \times FI_{f,j} \times EF_{k,f,j}$
Data required See following table for more details	$\boldsymbol{Em_{k,f}}$ *= Amount of pollutant k emitted by burning of fuel f (kg)* $\boldsymbol{tkm_f}$ *= Tonne-km travelled using vessels powered by fuel f (tkm)* $\boldsymbol{FI_f}$ *= Fuel intensity for vessel using fuel f (tonne fuel/tkm)* $\boldsymbol{EF_{k,f}}$ *= Emission factor specific to fuel f and pollutant k (kg/tonne)**	$\boldsymbol{Em_{k,f,j}}$ *= Amount of pollutant k emitted by burning of fuel f using vessel engine type j (kg)* $\boldsymbol{tkm_{fj}}$ *= Tonne-km travelled using vessel engine j powered by fuel f (Tonne-km)* $\boldsymbol{FI_{f,j}}$ *= Fuel intensity for vessel using fuel f and vessel engine type j (tonne fuel/tkm)* $\boldsymbol{EF_{k,f}}$ *= Emission factor specific to fuel f, pollutant k, and vessel engine type j (kg/tonne)**
Disaggregation	Activity data (total amount of fuel consumed) is disaggregated by fuel. E.g., Bunker fuel oil	Activity data (total amount of fuel consumed) is disaggregated by fuel and vessel engine type. E.g., bunker fuel oil burned by gas turbine **Tier 2 emission factors with separate disaggregation categories are available for small boats, different efficiency engines.**

	TIER 1	TIER 2
Notes	In the shipping sector an additional step is needed to quantify air pollutants, which considers emission control technologies. Table 15 at the end of this section shows the emission reduction percentage based on different control technologies.	
	Equation "*a*" can be applied when the total fuel consumption is known for the users own operations. In some instances, it may potentially result in an overestimate of emissions as this equation cannot account for emissions attributed to a specific load, or cargo transported, but rather it accounts for all air pollutants that were emitted from the consumption of the total amount of fuel used. Equation "*b*" replaces total fuel consumption with tonne-kilometres transported (tkm), divided by fuel intensity (tonne fuel per tkm), providing a way of allocating emissions to a portion of the load. It should be noted that this remains a fuel-based methodology, since the emission factors in Equation b are expressed in kg/tonne-fuel consumed. This may be particularly relevant to companies whose freight is transported alongside cargo from other companies in the same vessel.	

Data required

To ensure consistency with the GLEC Framework, Table 13 summarizes the core data inputs required for emission calculations, their units, sources of availability, and the aligned data assumptions that must be applied.

Table 13 Data Requirements and GLEC-Aligned Assumptions for Emission Calculations

Data	Units	Data availability	GLEC aligned - data assumptions
Fuel Consumption (FC)	tonne	This parameter is usually calculated by the user, or provided by a supplier.	If the data for fuel consumption is in litres or other unit, it must be converted. The GLEC Framework Section 3, Module 1 have some standard density factors which can be used.
Emission factor (EF)	kg / tonne fuel	See below for EFs for Tier 1, further emission factors for Tier 2 are in Appendix I.	In the shipping sector an additional step is needed to quantify air pollutants, which considers emission control technologies. The below sections outline the emission reduction percentage to be applied based on different control technologies.
Transport activity	tkm (tonne-km)	Transport activity (tkm) is usually calculated or provided to the user by a supplier.	Transport activity must always be calculated in accordance with the GLEC Framework.

Data	Units	Data availability	GLEC aligned - data assumptions
		Sometimes in the form of simply distance (km) and shipment mass (or load transported) (tonnes). *tkm = distance (km) × mass (tonnes).*	• In containerised transport, TEU is commonly used instead of mass. If the actual cargo mass per TEU is unknown, apply the standard factor of 10 tonnes per TEU. Additional conversion factors are provided in the GLEC Framework (Section 1, Chapter 4, "Shipment mass") • Distance transport activity should preferably be calculated using either the SFD, which accounts for the complete navigational route and applicable maritime channels for the vessel in question, or GCD. When using actual distance, a mode-specific DAF must be applied (see GLEC Framework, Section 3, Module 2).
Fuel intensity (FI)	tonne fuel / tkm	Primary fuel consumption (kg fuel) can be used and divided by the transport activity (tkm) to obtain the FI value. Default FI for shipping is calculated by dividing emission intensity (EI) by the GHG fuel emission factor (EF_{GHG}), as described in Section 1.4.2 of this guidance. Sea EF_{GHG} are listed in Section 3, Module 1 (Table: "Marine Fuel Emission Factors"), and EI values in Section 3, Module 2 (Table: "Sea Transport Emissions Intensity Values"). The same can be applied to Inland Waterways with EI values in	

Data	Units	Data availability	GLEC aligned - data assumptions
		Section 3, Module 2 (Table: "Inland Waterways Transport Emission Intensity Values")	

Emission Factors

Default emission factors for Tier 1 shipping air pollutants are reproduced from the EMEP/EEA guidebook (2023) in Table 14. Emission factors for the Tier 2 method can be found in Appendix I, Table S7. Additional emission factors for Tier 2 shipping with abatement can be found in Table S8.

Table 14 Tier 1 emission factors for shipping pollutants (Gas Oil/Diesel)

Fuel Category	Emission Factors (kg/tonne-fuel-consumed)					
	CO	NOx	PM10	BC	PM2.5	SO2
Bunker fuel oil	3.67	69.1	5.2	0.09	-	19.2
Marine Diesel Oil/ Marine Gas oil	3.84	72.2	1.07	0.04	-	1.82
LNG	13.8	4.92	0.00124	0.0000249	0.00106	0
Gasoline	573.9	9.4	9.5	0.051	9.5	202

SO_2 calculations

Maritime users may be familiar with the disaggregation of Bunker Fuel Oil by sulphur content: high sulphur fuel oil (HSFO), very low sulphur fuel oil (VLSFO), and ultra-low sulphur fuel oil (ULSFO). These classifications will have a significant effect on SO_x emissions due to their varying sulphur content. If the user has information about the sulphur content of these materials, then the emission factor can be calculated from equation 21, where the emission factor is in kg SO_2/tonne of fuel, and the S% is the percentage of sulphur in the fuel before burning.

Equation 21 $EF_{(SO2)} = 20 \times S\%$

EF_{SO2} = emission factor for SO_2
S% = percentage sulphur content in the fuel

Shipping and Emission Controls

According to the EMEP/EEA guidebook (2023) emission controls can include the following categories:

- Improved engine design, fuel injection systems, electronic timing, etc. to obtain optimum efficiency (optimising CO_2 emissions) reducing PM and VOC emissions
- Exhaust gas recirculation (EGR) where a portion of the exhaust gas is routed back to the engine charge air whereby the physical properties of the charge air are changed. For marine diesel engines, a typical NOx emission reduction of 10–30 % can be found. This technique has not yet been in regular service for ships
- Selective catalytic reduction (SCR) where a reducing agent is introduced to the exhaust gas across a catalyst. Hereby NOx is reduced to N_2 and H_2O. However, this technology imposes severe constraints on the ship design and operation to be efficient. A reduction of 70–95 % in NOx can be expected applying this technology. The technology is in use in a few ships and is still being developed

- Selective non catalytic reduction (SNCR) where the exhaust gas is treated as for the SCR exhaust gas treatment technique, except the catalyst is omitted. The process employs a reducing agent, supplied to the exhaust gas at a prescribed rate and temperature upstream of a reduction chamber. Installation is simpler than the SCR but needs a very high temperature to be efficient. Reductions of 75–95 % can be expected. However, no installations have been applied yet on ships
- Scrubber (Exhaust Gas Cleaning System) is an emission control system that is used in order to reduce SOx and PM emissions by adding sea water or fresh water and chemical substances in the exhaust gas

In the shipping sector an additional step needed to quantify air pollutants, which is emission control technologies. Table 15 shows the emission reduction percentage based on different control technologies. The positive values indicate a reduction of pollutants through the emission control system, while the negative values indicate an increase of pollutants through the emission control system, categories marked as N/A are not applicable.

Table 15 Emission reduction percentage of different emission control technologies Source: EMEP/EEA guidebook (2023)

Emission Abatement	Fuel	CO (%)	NO_x (%)	SO_2 (%)	PM (%)
Wet scrubber	Bunker fuel oil[d]	-3.61	5.84	98.8	31.6
	MDO/MGO	N/A	N/A	N/A	N/A
SCR	Bunker fuel oil	-63	89.6	23.5	34.8
	MDO/MGO	-55.8	70.2	6.57	6.1
DOC	Bunker fuel oil	42.9	-0.63	-1.3	50
	MDO/MGO	99.2	20.4	0	-113
DPF	Bunker fuel oil	N/A	N/A	N/A	N/A
	MDO/MGO	0	0	-1.5	91.7
SCR+Scrubber	Bunker fuel oil	-119	80.1	99.7	34.8
	MDO/MGO	N/A	N/A	N/A	N/A
SCR+DPF	Bunker fuel oil	N/A	N/A	N/A	N/A
	MDO/MGO	-55.8	92	4	96
DPC + Scrubber	Bunker fuel oil	42.9	5.66	99.1	50
	MDO/MGO	N/A	N/A	N/A	N/A

The emissions from abated technologies can be calculated using Equation 22. The resulting emission factors for shipping with abatement technologies as calculated from the percentage changes in Table 15 are shown in Appendix 1, Table S8.

[d]**Note:** Although different categories of bunker fuel are in use (HSFO, VLSFO, ULSFO), the emission factors applied here are directly derived from the EMEP/EEA air pollutant emission inventory guidebook. These factors are reported at an aggregated level and do not differentiate by specific fuel type. As a result, the methodology reflects this limitation and applies uniform values across all bunker fuel categories.

Equation 22 $RevEF_{k,f,e} = \sum_c (EF_{k,f,e}\left(1 - \frac{Cc}{100}\right) \times f_c)$

where:
$RevEF_{k,f,e}$= revised biofuel mix-specific emission factor of pollutant k, fuel type f, and engine type e (kg/tonne)
$EF_{k,f,e}$ = fuel biofuel mix-specific emission factor for pollutant k, fuel type f, and engine type e (kg/tonne)
C_c = correction factor for emission control technologies.
f_c = distribution of emission control technology on the considered fleet

Distribution of emission control technology on the considered fleet is calculated as follows:

Equation 23 $f_c = fleet\ with\ specific\ emission\ control\ technology/total\ fleet$

Biofuel use in Shipping

The use of biofuels can have a significant impact on the emission of air pollutants (Table 16). To accurately reflect the impact from the use of biofuel, it is essential to apply a corrected emission factor when estimating emissions from biofuel blends. The reduction of emissions is mainly due to lower sulphur content in the biofuels, which leads to a significant reduction in the emissions of SO_x and PM.

Table 16 Emission performance of biofuels compared to fuel oil as baseline. Increases and decreases represent a range of changes that occur from the different fuel types

Biofuel	Reference Fuel	Blend	Emission reductions compared with reference fuel		
			SOx	NOx	PM
FAME	LSHFO (1% S)	100%	89%	-13% (increase)	75%
	MGO	100%	100%	0	38%
	ULSD (0.001% S)	100%	-	12% - 29%	-
	MGO and LSHFO (0.05% S; compiled with Tier III)	100%	99%	0	38% (MGO); 90% (LSHFO)
Hydrotreated renewable diesel	ULSD	50%	100%	1%- 13%	0% to 38% (20% weighted average)
	MGO (0.05% S)	100%	100%	0% - 20%	-30% (increase)
FT Diesel	MGO (0.05% S)	100%	100%	0	24%
	MGO (0.05% S)- with 4 stroke engines	100%	100%	8% - 20%	-18% (increase) – 16% (increase)
	MGO	10%	•	3% - 11%	4% - 6%
Methanol	MGO (0.05% S; compiled with Tier II)	100%	100%	81%	61%
	LSHFO (1% S)	100%	100%	82%	100%
	HFO (compiled with Tier II)	100%	100%	30% - 50%	90%
	LFO	100%	100%	51%	-
DME	HFO	20% & 40%	100%	-20% to -26% (increase)	23% to 58%

Source: ICCT, 2020

Once the user gets the revised EF, the user can use it for both Tier 1 and Tier 2 equation for estimating pollution. User should use this revised emission factor only in case the vessel is running on biofuel (Equation 24).

Equation 24 $$RevEF_{k,f,e} = \sum_c \left(EF_{k,f,e} \times \left(1 - \frac{Cc}{100}\right)\right)$$

Where,

$RevEF_{k,f,e}$ *= revised fuel biofuel mix-specific emission factor of pollutant k, fuel type f, and engine type e (kg/tonne)*

$EF_{k,f,e}$ *= fuel biofuel mix-specific emission factor of pollutant k, fuel type f and engine type e (kg/tonne)*

C_c *= correction factor for biofuel*

For expanded information, context and example calculations the user is encouraged to visit Chapter 3, Section 3.3 in the CCAC/SEI Integrated Guide for Business. For expanded information on the methods and emission factors users are referred to the EMEP/EEA guidebook Chapter 1.A.3.d.

2.5.5 Aviation

The EMEP/EEA guidebook considers fuel combusted as activity data for Tier 1 aviation. When estimating air pollutant emissions from freight transported by air, the activity data should be disaggregated by fuel (Table 17). Tier 1 emission factors published in the EMEP/EEA guidebook for aviation are expressed in kilograms of pollutant per tonne of fuel consumed.

Whilst the Tier 1 methodology accounts for a total mass of fuel consumed during a journey, Tier 2 disaggregates further by treating the emissions for landing and take-off operations (LTOs) as separate from the emissions produced during Climb/Cruise/Descent (CCD). Since this level of detail and the resultant complexity is beyond the scope of this guidance, only a Tier 1 methodology is detailed below. Users wishing to find details of Tier 2 and Tier 3 methodologies for aviation are directed to the EMEP/EEA guidebook.

Table 17 Summary of data inputs for Tier 1 approach.

	TIER 1
Overview	The Tier 1 method uses the total amount of fuel consumed, disaggregated by fuel type.
Equation (a)	**Equation 25** $$\boldsymbol{Em_{k,f} = FC_f \times EF_{k,f}}$$
Data required See following table for more details	*Where,* $\boldsymbol{Em_{k,f}}$ *= emissions from aircraft of the specific pollutant k, and fuel f (kg)* $\boldsymbol{FC_f}$ *= fuel consumption of fuel f (tonne)* $\boldsymbol{EF_{k,f}}$ *= emission factor for pollutant k, and fuel f (kg/tonne of fuel consumed)*
Alternative Equation (b)	**Equation 26**

	TIER 1
	$Em_{k,f} = tkm_f \times FI_f \times EF_{k,f}$
	$\boldsymbol{Em_{k,f}}$ = *Amount of pollutant k emitted by burning of fuel f (kg)* $\boldsymbol{tkm_f}$ = *Tonne-km travelled using aircraft powered by fuel f (tkm)* $\boldsymbol{FI_f}$ = *Fuel intensity for aircraft using fuel f (tonne fuel/tkm)* $\boldsymbol{EF_{k,f}}$ = *Emission factor specific to fuel f and pollutant k (kg/tonne)**
Disaggregation	Activity data (total amount of fuel consumed) is disaggregated by fuel. E.g., Jet gasoline burned.

Data required

To ensure consistency with the GLEC Framework, Table 18 summarises the core data inputs required for emission calculations, their units, sources of availability, and the aligned data assumptions that must be applied.

Table 18 Data Requirements and GLEC-Aligned Assumptions for Emission Calculations

Data	Units	Data availability	GLEC aligned - data assumptions
Fuel Consumption total	tonne	This parameter is usually calculated by the user or provided by a supplier.	If the data for fuel consumption is in litres or other unit, it must be converted. The GLEC Framework Section 3, Module 1 have some standard density factors which can be used. Air Fuel emission factors for Jet Kerosene are included in the GLEC Framework Section 3, Module 1 and may assist in conversions depending on the data available to the user.
Emission factor (EF)	kg / tonne fuel	See below for EFs for Tier 1.	N/A
Transport activity	tkm OR tonne-km	Transport activity is usually calculated or provided to the user by a supplier. Sometimes in the form of simply distance (km) and shipment mass (or load transported) (tonnes).	Transport activity must always be calculated in accordance with the GLEC Framework. **Actual mass in tonnes** is to be used. If this is not available, estimated weight based on the

Data	Units	Data availability	GLEC aligned - data assumptions
		GCD should be used for calculations.	mass of the cargo can be applied. The GLEC Framework provides references to industry averages to use as default in Section 3, Module 2. **Great Circle Distance** (GCD): GCD or "as the crow flies," is primarily used in air transport, it offers a potential harmonised measure across supply chains but is not yet widely adopted beyond aviation. It should be calculated between the origin and destination airport of each flight leg.
Fuel intensity (FI)	tonne fuel / tkm	Primary fuel consumption (kg fuel) can be used and divided by the transport activity (tkm) to obtain the FI value. In the aviation sector the fuel intensity is recorded as MJ fuel/tkm. The air fuel emission factors in Section 3, Module 1 can assist with converting to kg fuel/tkm	If neither of the above exist, a default fuel intensity value can be derived from converting between the air fuel emission factors (Section 3, Module 1) and the emission intensity factors Section 3 Module 2). This method is explained in this guidance in section 2.1.

Emission factors

Some default emission factors for Tier 1 aviation air pollutants are reproduced from the EMEP/EEA guidebook (2023) in Table 19.

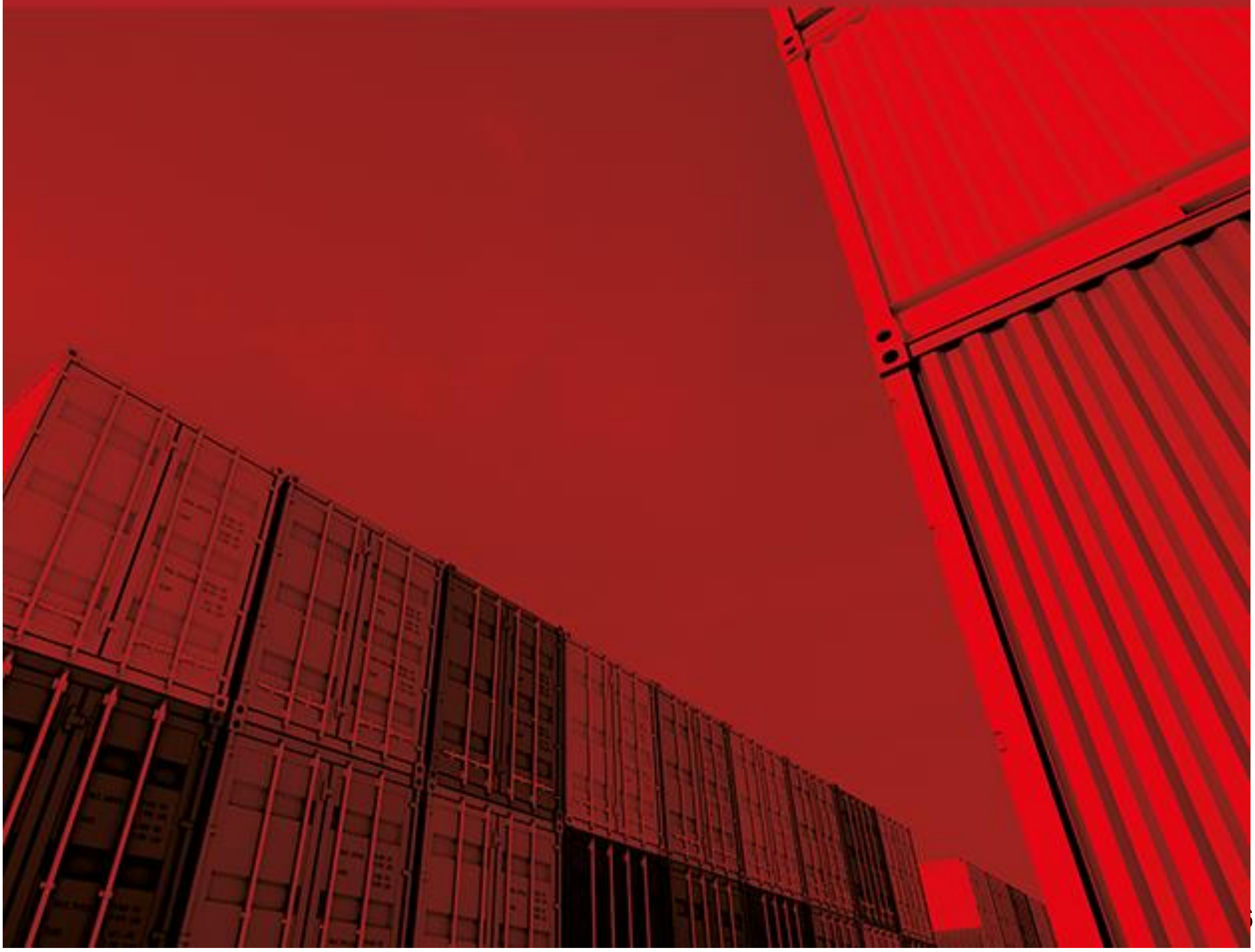
Table 19 Tier 1 emission factors for aviation air pollutants

Fuel Category	Emission Factors kg/tonne fuel		
	CO	**NO_x**	**SO_2**
Jet Gasoline and Aviation Gasoline	1200	4	1

For expanded information, context and example calculations the user is encouraged to visit Chapter 3, Section 3.3 in the CCAC/SEI Integrated Guide for Business. For expanded information on the methods and emission factors users are referred to the EMEP/EEA guidebook Chapter 1.A.3.a.

3

Further Considerations for The Inventory Complier



3. Further information for the inventory compiler

3.1 Compiling the results

The methods of this guidance enable users to quantify black carbon (BC), particulate matter (PM), sulphur oxides (SO_x), and nitrogen oxides (NO_x) that are emitted from different modes of transport across a company's value chain. Once this quantification is complete then the user will have developed an emissions inventory for air pollutant emissions.

An emissions inventory is a database that records the quantity of air pollutants released into the atmosphere from key emitting sources over a defined period (one or more years). Companies that develop inventories using this guidance can use them to identify significant air pollutant sources throughout their value chain. Developing an emissions inventory is therefore an important aspect of air quality management, being considered a foundational step in understanding the primary emission sources of different pollutants.

Key considerations for the inventory compiler are listed below:

1. Mapping all assumptions: As seen above in Section 2 (methods), the availability of primary data or default data and the level of granularity will decide the choice of method. It is important for the inventory compiler to clearly, consistently and transparently map those assumptions which may have an impact on the magnitude of air pollutants calculated and may come with higher or lower uncertainty. The section above considers assumptions from the GLEC Framework, which provides a set of default values which can be used in the absence of primary or company-specific activity data. This approach can be used as a starting point, with the use of well-established industry averages and the goal of transitioning towards the use of primary data in the future.
2. Aligning with the GLEC Framework: calculations must ensure transparency, consistency, and comparability in emissions accounting. This requires clearly defining boundaries and scopes, calculating distances in accordance with the GLEC Framework, and systematically including empty running to avoid underestimating emissions. Primary data should be prioritised over defaults, and robust, recognised emission factors must be applied consistently. Exclusions such as irregular detours (e.g., weather, congestion) should be avoided to maintain methodological integrity. Finally, results must be reported in standardized units with full documentation of data sources, assumptions, and calculation methods to enable verification.
3. Mapping which methods are used (e.g., Tier 1, Tier 2, or a mix): It is good practice to note which Tier has been used to estimate air pollutant emissions from different modes of transport. Keeping a record of the Tiers that have been used can be very useful to the inventory compiler as it will give them an understanding of which modes of transport are using a higher Tier (e.g., Tier 2) and where the air pollutant emissions calculations have been estimated using a Tier 1 method, in which case there is room for improvement and moving the calculations to a higher Tier.
4. Reporting each pollutant separately: While in the GHG accounting and reporting space it is common to report on all the different GHGs together using what is known as 'carbon dioxide equivalent' (CO2e), for air pollutant emissions, it is best practice to report each pollutant separately. This means the user will have to report PM_{10}, $PM_{2.5}$, BC, SO_x and NO_x, separately from each other.

Once the calculations are completed, the results can be used for reporting and declaring emissions. The reporting can allow an organisation to share the results, ensuring transparency

and the provision of accurate information and enabling various stakeholders to effectively assess environmental impacts and sustainability performance.
The report should ensure that the information presented is accurate, transparent and of high quality. Supporting information is crucial to ensuring that emissions data is reliable and actionable. A report generated using this guidance should provide a clear explanation of how the air pollutant emissions were calculated and specify any omitted sources with justifications for their exclusion. The report can be produced at least on an annual basis. However, it may be issued more frequently if required, especially in cases of process changes or when assessing different development scenarios. The report must also explicitly define the period covered by the emissions data. Good examples of emissions inventories built using these methodologies is the reporting by Maersk in their annual sustainability report and in the DFDS, IKEA and DHL sustainability reports.

3.2 Looking forward

3.2.1 Scenario Analysis

This section is outside the scope of the guidance and is provided as supplementary information. While the guidance does not cover the full process of developing emissions scenarios, it is recommended that users assess how the information generated for the air pollutant emissions inventory may also be applied to the evaluation of potential future emissions.

Business-as-Usual Scenario(s)

The role of a Business-as-Usual (BaU) inventory is to provide reference data to compare historical emissions data or planned mitigation strategy scenarios to. This could include the expected changes in emissions for a company's operations if no policy changes or mitigation interventions are implemented.

Different BaU scenarios can be developed to reflect different assumptions about how key emitting factors may change in the future. For example, a company may expect that their energy consumption will continue to increase in certain markets, but transport will decrease in that market (BaU scenario 1). If there is a possibility that both the energy consumption and transport will decrease, then an alternative BaU scenario can be developed (BaU scenario 2). These can therefore provide useful insight into the air pollution impact of different business decisions.

Mitigation Scenario(s)

The changes in expected emissions due to implemented sustainability or mitigation strategies are important to identify by comparing projected emission inventories from mitigation scenarios to the BaU scenario. These can either reflect:

- an 'Existing Commitments' scenario where the user can calculate an inventory for the mitigation strategies and measures that are already part of a company's GHG strategies, or
- an 'Increased Ambition' scenario which considers these in addition to key emitting sectors and parts of the value chain where the private sector doesn't normally focus, or where air pollutant-specific measures are required to further reduce air pollutant emissions when compared to the Existing Commitments scenario.

3.2.2 Mitigation Strategies

Estimating air pollutant emissions can give a company or organisation the capacity to identify transport modes in their supply chain which are more polluting than others. To mitigate the emissions, two broad strategies can be used:

1. Mitigation Strategies: Technological
2. Mitigation Strategies: Policy Framework

Accounting and reporting of air pollutant emissions serves as a systematic tool to identify emission hotspots, supporting the development of effective mitigation plans. By quantifying the amount of each pollutant released and determining the main emission sources, companies can establish measurable targets and goals for emission reduction. These targets can be integrated into corporate Key Performance Indicators (KPIs), enabling continuous progress tracking, evaluation of alternative scenarios, and benchmarking against other organizations to identify areas for improvement. This structured approach facilitates the design and implementation of comprehensive emission reduction plans.

Mitigation Strategies: Technological

From a technology point of view, transport related emissions are determined by three main elements: the engine emission abatement, fuel use, and distance travelled.

Engine Abatement: In recent years diesel engine technology has evolved considerably to limit air pollution. Modern diesel engines with emission control systems combine significant fuel efficiency and near-zero NOx emissions, making them one of the most cost-effective solutions for reducing transport emissions. In developing countries, the role of diesel engines with emission control systems is expected to play a significant role in its economic viability and in limiting air pollution for even longer. Alternatively, companies can opt for retrofitting their freight vehicles to new engine standards to reduce air pollutants emissions.

Fuel use: Combustion from fossil fuels is one of the major sources of particulate matter. The replacement of high-emission fuels such as coal, heavy fuel oil, or biomass with cleaner alternatives like natural gas, low-sulphur fuels, or renewables can significantly reduce emissions of key air pollutants including PM, SO_2, and NO_x. Furthermore, the adoption of low-sulphur fuels has directly contributed to the reduction of SO_x emissions from road freight vehicles (European Commission, 2019).

Distance travelled: Reducing the distance travelled in freight operations is a proven strategy for lowering emissions of air pollutants such as PM, NO_x, and non-methane volatile organic compounds (NMVOCs). So, to reduce distance travelled companies can explore **route rationalisation** – which is optimising routes for delivery, transit etc to improve efficiency, reduce costs, and enhance service quality by minimising travel distance, fuel intensity.

Logistics consolidation: Logistics consolidation is combining multiple smaller shipments into one single shipment to reduce cost and multiple trips.

Mitigation Strategies: Operational Framework

A common way to improve GHG and air pollution emissions is to alter the routine systems and behaviours a company uses to reduce impact. Decisions such as the vehicles used to transport goods, and reduced energy use are all non-technological ways to reduce this impact.

Often, the activities emitting pollutants across the value chain are either legacy problems, such as old, poorly insulated buildings, or outsourced decisions such as aging vehicles in a freight forwarders fleet. The impact of internal policies such as choosing to work with cleaner third parties along the value chain are also worth calculating.

Common Air Pollutant Sources and Mitigation

Table 20 provides a summary of the main sources of air pollutant emissions from the transport sector and the corresponding mitigation measures, such as the adoption of cleaner fuels, advanced emission control technologies, fleet electrification, and logistics optimisation.

Table 20 Overview of Key Air Pollutant Emission Sources and Associated Control Strategies

Pollutant	Main Sources	Mitigation Measures
Black Carbon (BC) and $PM_{2.5}$/PM_{10}	Diesel combustion	Diesel Particulate Filters, Cleaner fuels (LNG, biofuels, renewable), Fleet renewal and electrification
Nitrogen Oxides (NO_x)	Engine combustion (diesel, marine, aviation)	Selective Catalytic Reduction, Optimised combustion and modern standards (Euro VI / Tier 4+), Electrification, Modal shift to rail/inland waterways
Sulphur Oxides (SO_x)	High-sulphur marine & heavy fuels	Ultra-low sulphur fuels, Scrubbers on ships, Shift from heavy fuel oil to LNG/renewables
All Pollutants	Overall freight activity & fuel use	Supply chain optimisation, Load consolidation - Shared logistics and digitalisation, AI-driven routing and multimodal transport

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Appendix I

EMEP/EEA guidebook reported emission factors and other data can be found in this appendix. Note these data are collected from the 2023 edition of the EMEP/EEA guidebook, and users wishing to find updated emission factors should use the EMEP/EEA 2023 data.

Table S1 Implementation years of the European emission standards

Vehicle Category	Type	Euro Standard	Start Date	End Date
Passenger Cars	All Petrol	PRE ECE		Up to 1971
		ECE 15/00-01	1972	1977
		ECE 15/02	1978	1980
		ECE 15/03	1981	1985
		ECE 15/04	1985	1992
		Improved Conventional	1985	1990
		Open Loop	1985	1990
		Euro 1	1992	1996
		Euro 2	1996	1999
		Euro 3	2000	2004
		Euro 4	2005	2008
		Euro 5	2010	2014
		Euro 6 a/b/c	2014	2019
		Euro 6 d-temp	2019	2020
		Euro 6 d/e	2021	2026
		Euro 7	2026 and later	
	All Diesel	Conventional		Up to 1992
		Euro 1	1992	1996
		Euro 2	1996	2000
		Euro 3	2000	2005
		Euro 4	2005	2010
		Euro 5	2010	2014
		Euro 6 a/b/c	2014	2019
		Euro 6 d-temp	2019	2020
		Euro d/e	2021	2026
		Euro 7	2026 and later	
	All LPG	Conventional		Up to 1991
		Euro 1	1992	1996
		Euro 2	1996	1999
		Euro 3	2000	2004
		Euro 4	2005	2009
		Euro 5	2010	2014
		Euro 6 a/b/c	2015	2016
		Euro 6 d-temp	2017	2019
		Euro d/e	2020	2026
		Euro 7	2026 and later	
	All CNG	Euro 4	2005	2009
		Euro 5	2010	2014
		Euro 6 a/b/c	2015	2016
		Euro 6 d-temp	2017	2019
		Euro 6 d/e	2020	2026
		Euro 7	2026 and later	
	All Petrol Hybrid	Euro 4		Up to 2009
		Euro 5	2010	2014
		Euro 6 a/b/c	2014	2019
		Euro 6 d-temp	2019	2020
		Euro 6 d/e	2021	2026
		Euro 7	2026 and later	
	All Petrol PHEV	Euro 6 a/b/c		Up to 2019
		Euro 6 d-temp	2019	2020
		Euro 6 d/e	2021	2026
		Euro 7	2026 and later	

	All Diesel PHEV	Euro 6 a/b/c		Up to 2019
		Euro 6 d-temp	2019	2020
		Euro 6 d/e	2021	2026
		Euro 7	2026 and later	
	All Battery Electric	Euro 6 a/b/c		Up to 2019
		Euro 6 d-temp	2019	2020
		Euro 6 d/e	2021	2026
		Euro 7	2026 and later	
Light Commercial Vehicles	All Petrol	Conventional		Up to 1993
		Euro 1	1993	1997
		Euro 2	1997	2001
		Euro 3	2001	2006
		Euro 4	2006	2010
		Euro 5	2011	2015
		Euro 6 a/b/c	2016	2017
		Euro 6 d-temp	2018	2020
		Euro d/e	2021	2026
		Euro 7	2026 and later	
	All Diesel	Conventional		Up to 1993
		Euro 1	1993	1997
		Euro 2	1997	2001
		Euro 3	2001	2006
		Euro 4	2006	2011
		Euro 5	2011	2015
		Euro 6 a/b/c	2015	2017
		Euro 6 d-temp	2018	2020
		Euro d/e	2021	2026
		Euro 7	2026 and later	
	All Battery Electric	Euro 6 a/b/c		Up to 2019
		Euro 6 d-temp	2019	2020
		Euro 6 d/e	2021	2026
		Euro 7	2026 and later	
Heavy Duty Trucks	All Petrol	Conventional		
	All Diesel	Conventional		Up to 1992
		Euro 1	1992	1995
		Euro 2	1996	2000
		Euro 3	2000	2005
		Euro 4	2005	2008
		Euro 5	2008	2013
		Euro 6 a/b/c	2013	2019
		Euro 6 d/e	2019	2028
		Euro 7	2028 and later	
	All CNG	Euro 6 d/e		Up to 2028
		Euro 7	2028 and later	
	All LNG	Euro 6 d/e		Up to 2028
		Euro 7	2028 and later	
Buses	All Diesel	Conventional		Up to 1992
		Euro 1	1992	1995
		Euro 2	1996	2000
		Euro 3	2000	2005
		Euro 4	2005	2008
		Euro 5	2008	2013
		Euro 6 a/b/c	2013	2019
		Euro 6 d/e	2019	2028
		Euro 7	2028 and later	
	All CNG	Euro 1		Up to 1995
		Euro 2	1996	2000
		Euro 3	2000	2005
		EEV	2005	2013
		Euro 6 d/e	2013	2028

		Euro 7	2028 and later	
	All Battery Electric	Euro 6 a/b/c		Up to 2019
		Euro 6 d/e	2019	2028
		Euro 7	2028 and later	
L-Category	All Moped and Micro-cars	Conventional		Up to 1999
		Euro 1	1999	2003
		Euro 2	2003	2006
		Euro 3	2006	2013
		Euro 4	2016	2020
		Euro 5	2020 and later	
	All Motorcycles	Conventional		Up to 1999
		Euro 1	1999	2003
		Euro 2	2003	2006
		Euro 3	2006	2013
		Euro 4	2016	2020
		Euro 5	2020 and later	

Table S2 Road transport Tier 2 air pollutants

Vehicle Category	Fuel Type	Vehicle weight category	Abatement	Emission factor (g/km)							
				PM_{10}	$PM_{2.5}$[1]	CO	NH_3	NMVOC	NO_x	BC[2]	N_2O
Road Transport-HDVs	Diesel	<=7.5 t	Conventional	0.333	0.333	1.85	0.0029	1.07	4.7	0.176	0.029
			Euro I	0.129	0.129	0.657	0.0029	0.193	3.37	0.068	0.005
			Euro II	0.061	0.061	0.537	0.0029	0.123	3.49	0.032	0.004
			Euro III	0.0566	0.0566	0.584	0.0029	0.115	2.63	0.030	0.003
			Euro IV	0.0106	0.0106	0.047	0.0029	0.005	1.64	0.006	0.006
			Euro V	0.0106	0.0106	0.047	0.011	0.005	0.933	0.006	0.017
			Euro VI	0.0005	0.0005	0.047	0.009	0.005	0.18	0.000	0.017
		7.5-16 t	Conventional	0.3344	0.3344	2.13	0.0029	0.776	8.92	0.177	0.029
			Euro I	0.201	0.201	1.02	0.0029	0.326	5.31	0.107	0.008
			Euro II	0.104	0.104	0.902	0.0029	0.207	5.5	0.055	0.008
			Euro III	0.0881	0.0881	0.972	0.0029	0.189	4.3	0.047	0.004
			Euro IV	0.0161	0.0161	0.071	0.0029	0.008	2.65	0.009	0.012
			Euro V	0.0161	0.0161	0.071	0.011	0.008	1.51	0.009	0.034
			Euro VI	0.0008	0.0008	0.071	0.009	0.008	0.291	0.000	0.033
		16-32 t	Conventional	0.418	0.418	1.93	0.0029	0.486	10.7	0.222	0.029
			Euro I	0.297	0.297	1.55	0.0029	0.449	7.52	0.157	0.008
			Euro II	0.155	0.155	1.38	0.0029	0.29	7.91	0.082	0.007
			Euro III	0.13	0.13	1.49	0.0029	0.278	6.27	0.069	0.004
			Euro IV	0.0239	0.0239	0.105	0.0029	0.01	3.83	0.013	0.012
			Euro V	0.0239	0.0239	0.105	0.011	0.01	2.18	0.013	0.034
			Euro VI	0.0012	0.0012	0.105	0.009	0.01	0.422	0.001	0.032
		>32 t	Conventional	0.491	0.491	2.25	0.0029	0.534	12.8	0.260	0.029
			Euro I	0.358	0.358	1.9	0.0029	0.51	9.04	0.190	0.012
			Euro II	0.194	0.194	1.69	0.0029	0.326	9.36	0.103	0.012
			Euro III	0.151	0.151	1.79	0.0029	0.308	7.43	0.080	0.007
			Euro IV	0.0268	0.0268	0.121	0.0029	0.012	4.61	0.014	0.018
			Euro V	0.0268	0.0268	0.121	0.011	0.012	2.63	0.014	0.053
			Euro VI	0.0013	0.0013	0.121	0.009	0.012	0.507	0.001	0.049
	Petrol	>3.5 t	Conventional	0	0.0000	59.5	0.0019	5.25	6.6	0	0.006
Road Transport-Light Commercial vehicles	Diesel		Conventional	0.356	0.356	1.34	0.0012	0.133	1.66	0.196	0.01
			Euro 1	0.117	0.117	0.577	0.0012	0.141	1.22	0.064	0.025
			Euro 2	0.117	0.117	0.577	0.0012	0.149	1.22	0.064	0.025
			Euro 3	0.0783	0.0783	0.473	0.0012	0.094	1.03	0.043	0.028
			Euro 4	0.0409	0.0409	0.375	0.0012	0.035	0.831	0.022	0.013
			Euro 5	0.001	0.001	0.075	0.0019	0.035	1.15	0.001	0.0013
			Euro 6 (Up to 2017)	0.0009	0.0009	0.075	0.0019	0.035	0.96	0.000	0.0013
			Euro 6 (2018-20)	0.0009	0.0009	0.075	0.0019	0.035	0.496	0.000	0.0013
			Euro (2021+)	0.0009	0.0009	0.075	0.0019	0.035	0.248	0.000	0.0013
	Petrol		Conventional	0.0023	0.0023	25.5	0.0025	3.44	3.09	0.000115	0
			Euro 1	0.0023	0.0023	8.82	0.0758	0.614	0.563	0.000115	0.003

			Euro 2	0.0023	0.0023	5.89	0.091	0.304	0.23	0.000115	0.006
			Euro 3	0.0011	0.0011	5.05	0.0302	0.189	0.129	0.000055	0.009
			Euro 4	0.0011	0.0011	2.01	0.0302	0.128	0.064	0.000055	0.009
			Euro 5	0.0014	0.0014	1.3	0.0123	0.096	0.064	0.00007	0.004
			Euro 6 (Upto 2017)	0.0012	0.0012	1.3	0.0123	0.096	0.064	0.00006	0.004
			Euro 6 (2018-20)	0.0012	0.0012	1.3	0.0123	0.096	0.064	0.00006	0.004
			Euro (2021+)	0.0012	0.0012	1.3	0.0123	0.096	0.064	0.00006	0.004

Table S3 Road transport Tier 2 alternative fuels

Vehicle category	Fuel	Weight Category	Abatement	PM2.5 (g/km)				CO (g/km)			
				B0	B10	B20	B100	B0	B10	B20	B100
Road Transport-HDVs	Diesel	<=7.5 t	Conventional	0.333	0.300	0.283	0.176	1.85	1.758	1.684	1.480
			Euro I	0.129	0.116	0.110	0.068	0.657	0.624	0.598	0.526
			Euro II	0.061	0.055	0.052	0.032	0.537	0.510	0.489	0.430
			Euro III	0.0566	0.051	0.048	0.030	0.584	0.555	0.531	0.467
			Euro IV	0.0106	0.010	0.009	0.006	0.047	0.045	0.043	0.038
			Euro V	0.0106	0.010	0.009	0.006	0.047	0.045	0.043	0.038
			Euro VI	0.0005	0.000	0.000	0.000	0.047	0.045	0.043	0.038
		7.5-16 t	Conventional	0.3344	0.301	0.284	0.177	2.13	2.024	1.938	1.704
			Euro I	0.201	0.181	0.171	0.107	1.02	0.969	0.928	0.816
			Euro II	0.104	0.094	0.088	0.055	0.902	0.857	0.821	0.722
			Euro III	0.0881	0.079	0.075	0.047	0.972	0.923	0.885	0.778
			Euro IV	0.0161	0.014	0.014	0.009	0.071	0.067	0.065	0.057
			Euro V	0.0161	0.014	0.014	0.009	0.071	0.067	0.065	0.057
			Euro VI	0.0008	0.001	0.001	0.000	0.071	0.067	0.065	0.057
		16-32 t	Conventional	0.418	0.376	0.355	0.222	1.93	1.834	1.756	1.544
			Euro I	0.297	0.267	0.252	0.157	1.55	1.473	1.411	1.240
			Euro II	0.155	0.140	0.132	0.082	1.38	1.311	1.256	1.104
			Euro III	0.13	0.117	0.111	0.069	1.49	1.416	1.356	1.192
			Euro IV	0.0239	0.022	0.020	0.013	0.105	0.100	0.096	0.084
			Euro V	0.0239	0.022	0.020	0.013	0.105	0.100	0.096	0.084
			Euro VI	0.0012	0.001	0.001	0.001	0.105	0.100	0.096	0.084
		>32 t	Conventional	0.491	0.442	0.417	0.260	2.25	2.138	2.048	1.800
			Euro I	0.358	0.322	0.304	0.190	1.9	1.805	1.729	1.520
			Euro II	0.194	0.175	0.165	0.103	1.69	1.606	1.538	1.352
			Euro III	0.151	0.136	0.128	0.080	1.79	1.701	1.629	1.432
			Euro IV	0.0268	0.024	0.023	0.014	0.121	0.115	0.110	0.097
			Euro V	0.0268	0.024	0.023	0.014	0.121	0.115	0.110	0.097
			Conventional	0.0013	0.001	0.001	0.001	0.121	0.115	0.110	0.097
Road Transport-Light Commercial vehicles	Diesel		Conventional	0.356	0.303	0.285		1.34	1.273	1.219	
			Euro 1	0.117	0.099	0.094		0.577	0.548	0.525	
			Euro 2	0.117	0.099	0.094		0.577	0.548	0.525	
			Euro 3	0.0783	0.067	0.063		0.473	0.449	0.430	
			Euro 4	0.0409	0.035	0.033		0.375	0.356	0.341	
			Euro 5	0.001	0.001	0.001		0.075	0.071	0.068	
			Euro 6 (Upto 2017)	0.0009	0.001	0.001		0.075	0.071	0.068	

			Euro 6 (2018-20)	0.0009	0.001	0.001		0.075	0.071	0.068	
			Euro (2021+)	0.0009	0.001	0.001		0.075	0.071	0.068	
b	Petrol	Mini	Euro 4					1.05	1.050	0.998	
			Euro 5					1.042	1.042	0.990	
			Euro 6 a/b/c					0.397	0.397	0.377	
			Euro 6 d-temp					0.397	0.397	0.377	
			Euro 6 d					0.397	0.397	0.377	
		Small	PRE ECE					40.792	40.792	38.752	
			ECE 15/00-01					32.242	32.242	30.630	
			ECE 15/02					24.21	24.210	23.000	
			ECE 15/03					24.779	24.779	23.540	
			ECE 15/04					14.286	14.286	13.572	
			Improved Conventional					12.13	12.130	11.524	
			Open Loop					12.597	12.597	11.967	
			Euro 1					5.463	5.463	5.190	
			Euro 2					3.359	3.359	3.191	
			Euro 3					3.148	3.148	2.991	
			Euro 4					1.05	1.050	0.998	
			Euro 5					1.042	1.042	0.990	
			Euro 6 a/b/c					0.397	0.397	0.377	
			Euro 6 d-temp					0.397	0.397	0.377	
			Euro 6 d					0.397	0.397	0.377	
		Medium	PRE ECE					40.792	40.792	38.752	
			ECE 15/00-01					32.242	32.242	30.630	
			ECE 15/02					24.21	24.210	23.000	
			ECE 15/03					24.779	24.779	23.540	
			ECE 15/04					14.286	14.286	13.572	
			Improved Conventional					5.712	5.712	5.426	
			Open Loop					7.178	7.178	6.819	
			Euro 1					4.962	4.962	4.714	
			Euro 2					2.998	2.998	2.848	
			Euro 3					2.827	2.827	2.686	
			Euro 4					0.954	0.954	0.906	
			Euro 5					0.946	0.946	0.899	
			Euro 6 a/b/c					0.397	0.397	0.377	
			Euro 6 d-temp					0.397	0.397	0.377	
			Euro 6 d					0.397	0.397	0.377	
		Large-SUV-Executive	PRE ECE					40.792	40.792	38.752	
			ECE 15/00-01					32.242	32.242	30.630	
			ECE 15/02					24.21	24.210	23.000	
			ECE 15/03					24.779	24.779	23.540	

			ECE 15/04					14.286	14.286	13.572	
			Euro 1					3.974	3.974	3.775	
			Euro 2					2.287	2.287	2.173	
			Euro 3					2.195	2.195	2.085	
			Euro 4					0.765	0.765	0.727	
			Euro 5					0.757	0.757	0.719	
			Euro 6 a/b/c					0.397	0.397	0.377	
			Euro 6 d-temp					0.397	0.397	0.377	
			Euro 6 d					0.397	0.397	0.377	
	Diesel	Mini	Euro 4					0.092	0.092	0.087	
			Euro 5					0.035	0.035	0.033	
			Euro 6 a/b/c					0.052	0.052	0.049	
			Euro 6 d-temp					0.041	0.041	0.039	
			Euro 6 d					0.04	0.040	0.038	
		Small	Conventional					0.667	0.667	0.634	
			Euro 1					0.415	0.415	0.394	
			Euro 2					0.295	0.295	0.280	
			Euro 3					0.093	0.093	0.088	
			Euro 4					0.092	0.092	0.087	
			Euro 5					0.035	0.035	0.033	
			Euro 6 a/b/c					0.052	0.052	0.049	
			Euro 6 d-temp					0.041	0.041	0.039	
			Euro 6 d					0.04	0.040	0.038	
		Medium	Conventional					0.667	0.667	0.634	
			Euro 1					0.415	0.415	0.394	
			Euro 2					0.295	0.295	0.280	
			Euro 3					0.093	0.093	0.088	
			Euro 4					0.092	0.092	0.087	
			Euro 5					0.035	0.035	0.033	
			Euro 6 a/b/c					0.052	0.052	0.049	
			Euro 6 d-temp					0.041	0.041	0.039	
			Euro 6 d					0.04	0.040	0.038	
		Large-SUV-Executive	Conventional					0.667	0.667	0.634	
			Euro 1					0.415	0.415	0.394	
			Euro 2					0.295	0.295	0.280	
			Euro 3					0.093	0.093	0.088	
			Euro 4					0.092	0.092	0.087	
			Euro 5					0.035	0.035	0.033	
			Euro 6 a/b/c					0.052	0.052	0.049	
			Euro 6 d-temp					0.041	0.041	0.039	
			Euro 6 d					0.04	0.040	0.038	
	LPG Biofuel	LPG Bifuel	Conventional					7.998	7.998	7.598	
			Euro 1					5.658	5.658	5.375	
			Euro 2					3.981	3.981	3.782	

			Euro 3					2.859	2.859	2.716	
			Euro 4					0.94	0.940	0.893	
			Euro 5					0.94	0.940	0.893	
			Euro 6 a/b/c					0.191	0.191	0.181	
			Euro 6 d-temp					0.191	0.191	0.181	
			Euro 6 d					0.191	0.191	0.181	
	Hybrid petro	Small	Euro 4					0.745	0.745	0.708	
			Euro 5					0.745	0.745	0.708	
			Euro 6 a/b/c					0.075	0.075	0.071	
			Euro 6 d-temp					0.075	0.075	0.071	
			Euro 6 d					0.075	0.075	0.071	
		Medium	Euro 4					0.649	0.649	0.617	
			Euro 5					0.649	0.649	0.617	
			Euro 6 a/b/c					0.075	0.075	0.071	
			Euro 6 d-temp					0.075	0.075	0.071	
			Euro 6 d					0.075	0.075	0.071	
		Large	Euro 4					0.46	0.460	0.437	
			Euro 5					0.46	0.460	0.437	
			Euro 6 a/b/c					0.075	0.075	0.071	
			Euro 6 d-temp					0.075	0.075	0.071	
			Euro 6 d					0.075	0.075	0.071	
	PHEV Petrol	Small	Euro 6 a/b/c					0.056	0.056	0.053	
			Euro 6 d-temp					0.056	0.056	0.053	
			Euro 6 d					0.056	0.056	0.053	
		Medium	Euro 6 a/b/c					0.056	0.056	0.053	
			Euro 6 d-temp					0.056	0.056	0.053	
			Euro 6 d					0.056	0.056	0.053	
		Large	Euro 6 a/b/c					0.056	0.056	0.053	
			Euro 6 d-temp					0.056	0.056	0.053	
			Euro 6 d					0.056	0.056	0.053	
	PHEV Diesel	Large	Euro 6 a/b/c					0.039	0.039	0.037	
			Euro 6 d-temp					0.031	0.031	0.029	
			Euro 6 d					0.03	0.030	0.029	
	CNG Biofuel	CNG Bifuel	Euro 4					0.94	0.940	0.893	
			Euro 5					0.94	0.940	0.893	
			Euro 6 a/b/c					0.379	0.379	0.360	
			Euro 6 d-temp					0.059	0.059	0.056	
			Euro 6 d					0.059	0.059	0.056	

Table S4 Non-road transport Tier 1 emission factors

Fuel	NFR sector	Pollutant	Units	Emission factor
Diesel	1.A.4.c.ii-Agriculture	BC	g/Tonne fuel	1111
		CH4	g/Tonne fuel	87
		CO	g/Tonne fuel	11469
		CO2	kg/Tonne fuel	3160
		N2O	g/Tonne fuel	136
		NH3	g/Tonne fuel	8
		NMVOC	g/Tonne fuel	3542
		NOx	g/Tonne fuel	34457
		PM10	g/Tonne fuel	1913
		PM2.5	g/Tonne fuel	1913
		TSP	g/Tonne fuel	1913
	1.A.4.c.ii-Forestry	BC	g/Tonne fuel	626
		CH4	g/Tonne fuel	49
		CO	g/Tonne fuel	7673
		CO2	kg/Tonne fuel	3160
		N2O	g/Tonne fuel	138
		NH3	g/Tonne fuel	8
		NMVOC	g/Tonne fuel	1997
		NOx	g/Tonne fuel	28471
		PM10	g/Tonne fuel	943
		PM2.5	g/Tonne fuel	943
		TSP	g/Tonne fuel	943
	1.A.2.g.vii and 1.A.4.a.ii	BC	g/Tonne fuel	1306
		CH4	g/Tonne fuel	83
		CO	g/Tonne fuel	10774
		CO2	kg/Tonne fuel	3160
		N2O	g/Tonne fuel	135
		NH3	g/Tonne fuel	8
		NMVOC	g/Tonne fuel	3377
		NOx	g/Tonne fuel	32629
		PM10	g/Tonne fuel	2104
		PM2.5	g/Tonne fuel	2104

		TSP	g/Tonne fuel	2104
	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii			
		Cadmium	mg/kg fuel	0.01
		Copper	mg/ kg fuel	1.7
		Chromium	mg/ kg fuel	0.05
		Nickel	mg/ kg fuel	0.07
		Selenium	mg/ kg fuel	0.01
		Zinc	mg/ kg fuel	1
		Benz(a)anthracene	µg/kg fuel	80
		Benzo(b)fluoranthene	µg/kg fuel	50
		Dibenzo(a,h)anthracene	µg/kg fuel	10
		Benzo(a)pyrene	µg/kg fuel	30
		Chrysene	µg/kg fuel	200
		Fluoranthene	µg/kg fuel	450
		Phenanthene	µg/kg fuel	2500
LPG	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	BC	g/Tonne fuel	11
		CH4	g/Tonne fuel	354
		CO	g/Tonne fuel	4823
		CO2	kg/Tonne fuel	2990
		N2O	g/Tonne fuel	161
		NH3	g/Tonne fuel	10
		NMVOC	g/Tonne fuel	6720
		NOx	g/Tonne fuel	285718
		PM10	g/Tonne fuel	225
		PM2.5	g/Tonne fuel	225
		TSP	g/Tonne fuel	225
Gasoline: four- stroke	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii			
		BC	g/Tonne fuel	8
		CH4	g/Tonne fuel	665
		CO	g/Tonne fuel	770368
		CO2	kg/Tonne fuel	3197

		N2O	g/Tonne fuel	59
		NH3	g/Tonne fuel	4
		NMVOC	g/Tonne fuel	18893
		NOx	g/Tonne fuel	7117
		PM10	g/Tonne fuel	157
		PM2.5	g/Tonne fuel	157
		TSP	g/Tonne fuel	157
Gasoline: two- stroke				
		BC	g/Tonne fuel	188
		CH4	g/Tonne fuel	17108
		CO	g/Tonne fuel	620793
		CO2	kg/Tonne fuel	3197
		N2O	g/tones fuel	17
		NH3	g/Tonne fuel	3
		NMVOC	g/Tonne fuel	227289
		NOx	g/Tonne fuel	2765
		PM10	g/Tonne fuel	3762
		PM2.5	g/Tonne fuel	3762
		TSP	g/Tonne fuel	3762

Table S5 Non-road transport Tier 2 air pollutants emissions factors

				Technology								
Fuel	NFR Sector	Pollutant	Units	< 1981	1981-1990	1991-Stage I	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	Stage V
Diesel	1.A.4.c.ii: Agriculture	BC	g/Tonne fuel	3221	2221	1074	727	483	416	74	73	9
		CH4	g/Tonne fuel	191	158	110	38	29	29	13	13	13
		CO	g/Tonne fuel	19804	17566	14147	6463	6104	6035	6087	6024	6077
		CO2	kg/Tonne fuel	3160	3160	3160	3160	3160	3160	3160	3160	3160
		N2O	g/Tonne fuel	122	129	137	138	138	139	139	139	139
		NH3	g/Tonne fuel	7	7	8	8	8	8	8	8	8
		NMVOC	g/Tonne fuel	7760	6439	4493	1544	1181	1173	544	530	526
		NOx	g/Tonne fuel	29901	37383	49002	30799	20612	12921	9318	1587	1861
		PM10	g/Tonne fuel	5861	4047	1974	947	624	550	99	99	59
		PM2.5	g/Tonne fuel	5861	4047	1974	947	624	550	99	99	59
		TSP	g/Tonne fuel	5861	4047	1974	947	624	550	99	99	59
	1.A.4.c.ii: Forestry	BC	g/Tonne fuel	3021	2052	1172	607	456	437	74	74	9
		CH4	g/Tonne fuel	183	143	121	35	29	29	13	13	13
		CO	g/Tonne fuel	19014	16045	14239	5919	5940	5947	5940	5947	6008
		CO2	kg/Tonne fuel	3160	3160	3160	3160	3160	3160	3160	3160	3160
		N2O	g/Tonne fuel	123	131	137	138	139	139	139	139	139
		NH3	g/Tonne fuel	7	7	8	8	8	8	8	8	8
		NMVOC	g/Tonne fuel	7423	5827	4907	1420	1160	1161	514	515	542

		NOx	g/Tonne fuel	33028	44030	49963	31344	20593	12845	9454	1586	1915
		PM10	g/Tonne fuel	5493	3731	2130	789	595	573	99	99	59
		PM2.5	g/Tonne fuel	5493	3731	2130	789	595	573	99	99	59
		TSP	g/Tonne fuel	5493	3731	2130	789	595	573	99	99	59
	1.A.2.g.vii and 1.A.4.a.ii	BC	g/Tonne fuel	3414	2369	2001	800	825	758	78	78	56
		CH4	g/Tonne fuel	199	171	144	42	39	36	15	13	23
		CO	g/Tonne fuel	20690	18890	16258	6639	7135	6826	6445	6019	7352
		CO2	kg/Tonne fuel	3160	3160	3160	3160	3160	3160	3160	3160	3160
		N2O	g/Tonne fuel	121	128	135	137	136	136	137	137	136
		NH3	g/Tonne fuel	7	7	8	8	8	8	8	8	8
		NMVOC	g/Tonne fuel	8077	6962	5851	1725	1587	1470	625	536	930
		NOx	g/Tonne fuel	26552	33942	43552	31077	22101	15653	11933	1570	7663A
		PM10	g/Tonne fuel	6207	4308	3642	1005	1034	950	98	98	116
		PM2.5	g/Tonne fuel	6207	4308	3642	1005	1034	950	98	98	116
		TSP	g/Tonne fuel	6207	4308	3642	1005	1034	950	98	98	116
Gasoline:												
	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	BC	g/Tonne fuel	352	239	193	184	215				214
		CH4	g/Tonne fuel	22483	19462	17284	16979	8517				8539
		CO	g/Tonne fuel	754523	699494	621083	620519	695237				694870
		CO2	kg/Tonne fuel	3197	3197	3197	3197	3197				3197

		N2O	g/Tonne fuel	12	16	16	18	20				20
		NH3	g/Tonne fuel	2	3	3	4	4				4
		NMVOC	g/Tonne fuel	298703	258562	229630	225579	113157				111450
		NOx	g/Tonne fuel	1050	1682	1852	3445	2495				2490
		PM10	g/Tonne fuel	7037	4786	3869	3683	4299				4278
		PM2.5	g/Tonne fuel	7037	4786	3869	3683	4299				4278
		TSP	g/Tonne fuel	7037	4786	3869	3683	4299				4278
Gasoline: four-stroke	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii											
		BC	g/Tonne fuel	7	7	8	8	8				8
		CH4	g/Tonne fuel	710	910	672	650	568				468
		CO	g/Tonne fuel	1214855	836966	768445	774457	804157				778282
		CO2	kg/Tonne fuel	3197	3197	3197	3197	3197				3197
		N2O	g/Tonne fuel	56	55	59	59	60				59
		NH3	g/Tonne fuel	4	4	4	4	4				4
		NMVOC	g/Tonne fuel	20182	25852	19082	18469	16126				13293
		NOx	g/Tonne fuel	2429	5743	7129	7088	6676				5354
		PM10	g/Tonne fuel	148	147	157	159	159				159
		PM2.5	g/Tonne fuel	148	147	157	159	159				159
		TSP	g/Tonne fuel	148	147	157	159	159				159

Table S6 Rail transport Tier 2 air pollutant emission factors

Technology	Line-haul Locomotives						Rail Cars						Shunting locomotives					
Pollutant	PM10	PM2.5	NH3	NMVOC	CO	NOx	NOx	CO	NMVOC	NH3	PM10	PM2.5	NOx	PM2.5	PM10	NMVOC	NH3	CO
Unit	kg/tonne						kg/tonne						kg/tonne					
Gas Oil/Diesel	1.2	1.1	10	4.8	18	63	39.9	10.8	4.7	10	1.1	1	54.4	2	2.1	4.6	10	10.8

Table S7 Shipping Tier 2 air pollutant emission factors

Engine Type	Fuel type	NOx	NOx	NOx	PM10	PM 2.5
		2000	2005	2010	-	-
		kg/tonne				
Gas Turbine	BFO	20	19.3	18.6	0.3	0.3
	MDO/MGO	19.7	19	18.3	0	0
Stream Turbine	BFO	6.9	6.6	6.4	2.6	2.4
	MDO/MGO	6.9	6.6	6.4	1	0.9

Table S8 Shipping Tier 2 air pollutant emission factors – abatement

Emission control technology	Fuel	CO	NO_x	SO_2	NMVOCs	PM_{10}
		kg/tonne of fuel				
Wet scrubber	Bunker fuel oil	3.80	65.06	0.23	0.80	3.56
	MDO/MGO	N/A	N/A	N/A	N/A	N/A
SCR	Bunker fuel oil	5.98	7.19	14.69	0.52	3.39
	MDO/MGO	5.98	21.52	1.70	0.38	1.00
DOC	Bunker fuel oil	2.10	69.54	19.45	0.84	2.60
	MDO/MGO	0.03	57.47	1.82	0.05	2.28
DPF	Bunker fuel oil	N/A	N/A	N/A	N/A	N/A
	MDO/MGO	3.84	72.20	1.85	1.75	0.09
SCR+Scrubber	Bunker fuel oil	8.04	13.75	0.06	0.52	3.39
	MDO/MGO	N/A	N/A	N/A	N/A	N/A
SCR+DPF	Bunker fuel oil	N/A	N/A	N/A	N/A	N/A
	MDO/MGO	5.98	5.78	1.75	0.38	0.04
DPC + Scrubber	Bunker fuel oil	2.10	65.19	0.17	0.84	2.60
	MDO/MGO	N/A	N/A	N/A	N/A	N/A