EcoTransIT World Methodology Report

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IVE - Ingenieursgesellschaft für Verkehrs- und Eisenbahnwesen mbH (IVE) is a consulting and software development company. With EcoTransIT World, IVE is providing the leading global software for calculating energy consumption, greenhouse gas emissions, air pollutants and external costs. IVE is responsible for the ongoing development, technical implementation and innovation of the EcoTransIT World software.

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The Institute for Energy and Environmental Research (ifeu) has established itself as an independent competence centre in the field of environmental research. The Institute's expertise covers areas such as the environmental impact of freight transport, energy supply and renewable energy, life cycle analysis, air pollution control, sustainable development, environmental impact assessment and environmental management.

Fraunhofer Institute for Material Flow and Logistics IML, Dortmund, Germany

The Fraunhofer Institute for Material Flow and Logistics (IML) contributes its expertise to the emission assessment of logistics hubs. The initial methodology was developed in cooperation with well-known industrial partners in the research project Green Logistics, is now aligned with ISO 14083 and the Global Logistics Emissions Council (GLEC) Framework.

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Foreword

Since its beginnings in 1999, EcoTransIT World (abbreviation for **Eco**logical **Trans**port **I**nformation **T**ool **World**wide) a has provided the most scientific and trusted greenhouse gas and air pollutants emissions calculation methodology. For this reason, it has always been developed in collaboration with various methodology stakeholders and scientific partners. Given that freight transportation and logistics activities currently contribute 8% of global greenhouse gas emissions, the industry needs a reliable and flexible tool to measure current and determine future emissions. IVE, together with our methodology partners, is continuously advancing our solutions to expand our leadership as the most trusted and forward-thinking emission calculator in the logistics sector.

Beyond software as a service – EcoTransIT World maintains and empowers a thriving community. From the very beginning, EcoTransIT World has been flanked by the EcoTransIT World Initiative (EWI) - an independent, industry-driven platform, uniting freight forwarders, logistics service providers, shippers, carriers and tool providers. Together with the EWI members, the methodology is continuously developed and harmonized to ensure scientific robustness, transparency, and practical relevance across the logistics sector. In line with the vision to increase transparency on the environmental impact of freight transport and to demonstrate the continuous improvement of the EcoTransIT World methodology, the EWI members have commissioned their scientists and IT partners to produce this methodology report.

To date, hundreds of member companies are part of the EWI. These members also thank their scientists and IT partners - INFRAS, ifeu, Fraunhofer IML and IVE - for their continued support of EWI's vision.

1 Introduction

1.1 Background and task

As freight transport mainly relies on conventional energy carriers like diesel, kerosene and heavy fuel oil, it significantly contributes to major challenges of the 21st century: pollution and climate change. According to the Sixth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), transport accounts for about a quarter of global energy-related carbon emissions. This contribution is rising faster than on any other energy end-use sector.

With this purpose in mind, EcoTransIT World aims to address:

- Freight forwarding companies aiming to reduce the environmental impact of their shipments
- Carriers and logistic providers facing growing demand from customers and legislation to measure their carbon footprint and decarbonize their transport chains.
- Political decision makers, consumers and non-governmental organisations which are interested in a thorough environmental comparison of logistic concepts across all transport modes.

The environmental parameters covered are energy consumption, carbon dioxide (CO_2), sum of all GHG (measured as CO_2 equivalents) and air pollutants, such as nitrogen oxides (NO_x), sulphur dioxide (SO_2), non-methane hydrocarbons (NMHC) and particulate matter (PM) and external costs as additional indicator.

The beginnings of EcoTransIT World go back to 1999 where the industries requested a scientifically based tool for the environmental comparison of freight shipments with transport modes. The initial version was published in 2003 with a regional scope limited to Europe. The version published in 2010 was expanded to a global scope and for the first time, EcoTransIT World enabled the calculation of environmental impacts of worldwide freight transport chains. For this purpose, the routing logistics of the tool as well as the information about environmental impacts of all transport modes (especially sea and air transport) were expanded. In the meantime, the methodology was updated considering new sources, data and knowledge. In this context the requirements of the new European standard EN 16258:2012 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services" were considered. Applicability and compliance with international guidelines were also a constant objective in subsequent developments, initially with the principles that have been developed in the

GLEC Framework since 2016. Finally, the latest important milestone was the publication of the international standard ISO14083, which enables global standardisation of emissions calculation in the transportation sector.

As a result, EcoTransIT World has developed into a widely used international instrument that

- covers all modes of transport (road, rail, air, ocean, inland waterways, logistic hubs)
- applies global transport routes, partly based on primary data
- and thus supports LSPs, carriers, shippers, tools and others in the practical application of reporting, scenario calculation or the creation of benchmarks.

1.2 Norms and frameworks (IVE)

1.2.1 ISO14083:2023

The international standard ISO 14083:2023 on "Greenhouse gases – Quantification and reporting of greenhouse gas (GHG) emissions arising from transport chain operations" is the globally recognized standard for GHG emissions accounting for the transport sector. It replaces the former EN 16258 "Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)".

With ISO 14083, further alignment in GHG emissions quantification and reporting of (global) logistics chains – covering both transport as well as transhipment operations – has been established and can be confirmed as follows.

- The calculation of energy consumption and GHG emissions (as CO_2 equivalents) by EcoTransIT World is in accordance with ISO 14083 and can be used in the context of the GLEC Framework and GHG Protocol (Corporate Standard).
- The conversion and emission factors are regularly updated based on the most recent scientific findings and the latest recognized data sources for each mode (e.g. HBEFA for road, Eurocontrol Small Emitters Tool for air, the IMO greenhouse gas reports and Clean Cargo/Container Shipping for ocean, etc.) and adapted to EcoTransIT World aggregation levels based on relevant fuel related parameters (size, Euro class, filling rate, biofuel share, street category) on a country specific level and updated regularly.
- This report outlines the methodology of today's EcoTransIT World calculation and reporting. Particularly regarding highlighting in which way mandatory requirements of ISO 14083 have been implemented, such as the scope of transport chains or data quality used.

1.2.2 GLEC Framework

The Global Logistics Emissions Council (GLEC) Framework established by Smart Freight Centre (SFC) was the first global recognized methodology to calculate logistics GHG emissions and formed the basis for ISO 14083. It allows companies to consistently calculate their GHG footprint across global multi-modal supply chains. The beginnings of this framework go back almost ten years. With version 3.0, released in 2023, GLEC Framework fully aligns with ISO 14083. The most recent version, v3.2, was released in October 2025.

EcoTransIT World was the first emission calculation tool certified to be compliant with the GLEC Framework. As part of the certification statement SFC confirmed calculation to be in line with well-to-wheel GHG emissions according to the scopes of the GHG Protocol Corporate Value Chain Accounting and Reporting Standard.

1.2.3 ISAE3402

Within IVE, the IT processes relating to EcoTransIT World have been certified according to the International Standard on Assurance Engagements (ISAE) 3402 standard. Those IT processes cover the following areas:

- Change Management (changes of methodology and features implemented in EcoTransIT World)
- Update of source data (import of flight schedules data, sea vessel data, carbon dioxide emissions and geographic information data in EcoTransIT World)
- Release rollout (rollout of releases to customer’s instances of EcoTransIT World)
- Monitoring and issue workflow (monitoring IT operations)
- Hosting / operations (setup hosting of servers for customer’s instances of EcoTransIT World)
- Security Management (ensuring that IT security standards are kept up to date in EcoTransIT World)

The implementation of internal controls throughout the entire process and development chain can thus be guaranteed and is certified annually by external auditors. A confirmation letter and the entire report can be requested by customers from IVE mbH.

2 Application and Functional Use

Various interfaces are available to EcoTransIT World users. These range from a freely available emissions calculator on the website to a professional business solution that can be used via standardized application programming interface (APIs) and / or CSV data upload.

2.1 Public Online Calculation Module

The emission calculator provided on the website www.ecotransit.org enables the calculation of emissions for individual freight transports. The calculation allows the integration of specific transport parameters and automatically sets intelligent default parameters if these are not individually defined.

The aim of the emissions calculator is to analyse individual transports in a targeted manner and, if necessary, to compare them with each other.

It should be noted that certain functionalities are not provided on the emission calculator of the website but can be selected additionally via the interfaces. The methodology described below refers in its entirety to the interfaces.

2.2 Application connectivity interfaces (API) via REST and SOAP XML

EcoTransIT World provides a service that allows users to directly connect their own systems to the platform through a standardized application connectivity interface (API). API is a structured interface designed for performing emission calculations for transport services through defined requests. User can choose between the REST or SOAP protocol, it utilizes JSON or XML format for data exchange, making it suitable for integration with various applications.

This API allows for single request calculations, accepting individual calculation requests that can include all transport modes and an unlimited number of via points. This flexibility enables accurate modelling of complex transport chains.

Each request undergoes validation and can be enriched with default parameters before being sent to the calculation module, ensuring that the calculations are based on accurate and complete data. The service generates a REST/SOAP response containing the calculation results, which include detailed emission data and additional relevant metrics.

Beside emission calculation the API solution offers additional request types, like location, transfer point or vehicle type request. They enable the operation of a company specific emission calculator website.

In summary, the SOAP XML or REST web service is a powerful tool for organizations seeking to automate and integrate emission calculations into their logistics and transport management systems. Both options offer a structured approach and comprehensive request types suitable for a wide range of applications in environmental impact assessment.

2.3 CSV File Mass Calculation

The CSV File Mass Calculation is an advanced feature, enabling users to perform batch processing of transport service calculations using CSV files. This functionality is particularly beneficial for organizations that manage large datasets and require systematic analysis of transport and logistic emissions.

Users can upload CSV files containing multiple entries for transport services, allowing for simultaneous calculations rather than processing each entry individually. Upon uploading, the system conducts rigorous validation checks to ensure data integrity and enriches the dataset by automatically filling in any missing information necessary for accurate calculations, such as geographic coordinates or transport modes.

Each transport entry within the CSV file is processed independently, considering various parameters, including distance, load factors, and vehicle types, to provide precise emissions and energy consumption metrics. After processing, the system generates comprehensive output files in multiple formats, such as CSV, Excel, and KML. These files include detailed results, error messages for any problematic entries, and summaries of the calculations performed. In addition, the CSV output files can be individually adapted using configurable output converters, allowing users to customize structure, field naming, and content according to their specific reporting or system-integration requirements. Users can track the status of their calculations through a dedicated job list interface, which provides essential information such as job ID, calculation status (e.g., pending, completed, failed), and the duration of each calculation process. This batch processing capability enhances operational efficiency by allowing organizations to focus on analysis rather than data entry. Automated validation and enrichment further reduce the likelihood of errors, ensuring calculations are based on high-quality data.

The multiple output formats cater to various analytical needs, enabling users to integrate results into existing reporting frameworks or visualization tools. In summary, the CSV File Mass Calculation feature is a powerful tool for organizations seeking to optimize their transport and logistics emission analysis, providing a streamlined approach to handling complex datasets.

Result Dashboard

The result dashboard is an additional module of the CSV File Mass Calculation and offers business intelligence functionalities. It integrates Microsoft Fabric (Power BI) and provides various KPIs, such as overview figures, transport mode breakdowns, map and region views, data quality and data set comparisons.

File Module

The integration of the File Module with SFTP (Secure File Transfer Protocol) provides a secure method for uploading and downloading files. Users can upload request files containing numerous transport services and download response files with calculation results through a secure SFTP interface.

2.4 Supplementary Modules

Beneath the emission calculation module, IVE provides supplementary modules to improve the calculation success rate and process workflow.

2.4.1 LogViewer

The LogViewer module allows companies to analyse the quality of their EcoTransIT World calculation results s. It provides insights into various metrics, including:

- number of calculations performed
- calculation time for each transport
- transport types used
- detailed information about failed calculations.

The LogViewer helps users to gain a clear understanding of the interface performance. Additionally, users can filter views and set up automatic reports to be sent via email at customizable intervals. The LogViewer works in conjunction with the LocationEditor, enabling users to identify and rectify issues in calculations and thereby systematically and efficiently increase the calculation success rate through targeted analysis and location data maintenance.

2.4.2 LocationEditor

The LocationEditor module allows users to add customer-specific locations that are not already available in the system. This is particularly useful to maintain the quality of Geographic Information System (GIS) data by continuously adding new locations as needed. This module enhances the overall functionality of EcoTransIT World by ensuring that users can work with the most accurate and relevant location data for their transport calculations.

Figure 1: The supporting role of the supplementary modules

2.4.3 UniversalUserManager (UUM)

The Universal User Manager (UUM) is a component of the EcoTransIT World system that facilitates user management across various applications. It provides a centralized interface for managing user accounts, roles, and permissions.

3 General methodology

3.1 System boundaries and basic definitions

The following sections provide an overview about the system boundaries as well as terms and definitions used. EcoTransIT World is aligned with the ISO 14083 requirements, which means, that the system boundaries as well as definitions are set in accordance with the international standard. In addition, EcoTransIT World extends the ISO 14083's scope by quantifying additional emissions like air pollutants and external costs of transport chains.

3.1.1 Transport chains, transport chain elements and transport ‘ or hub operation categories

EcoTransIT World allows the calculation of different environmental impact categories (see chapter 0) for a single transport from A to B or for complex transport chains using different transport modes and hubs. According to the ISO14083, the **transport chain** (TC) shall be broken down into discrete, sequential **transport chain elements** (TCEs) that reflect the related vehicle types or hubs that carry, handle or transfer the freight as part of the whole transport chain [ISO 14083, 2023]. Each of these TCEs shall then be related to a corresponding **transport operation** (TO) or **hub operation** (HO), which is the operation of the vehicle(s) or the hub(s) for this transport chain element.

When determining the energy consumption and leakage of refrigerants caused by the related TO or HO, the overall to 0. Moreover, TOCs may have different levels of granularity: such as a single vehicle on a single journey or on a round-trip. TOCs can also consist of all vehicle roundtrips for one type of vehicle or of one route or even of all vehicle roundtrips in a network in which the transport chain element in question lies or would lie (for future transport operations). In the end, the energy consumption and refrigerant leakage and the related emission intensity for the entire TOC needs to be determined and corresponding GHG emissions of transport chain elements and transport chains calculated.

A comparable approach for transshipment at logistics hubs is established in EcoTransIT World: Characteristics such as the number, type and nature of hub operations, inbound/outbound transport mode or the nature of freight handled, and the relevance of temperature control of goods can be considered. Further details are provided in chapter 3.6 and 10.

system in which the operation takes place shall be considered. For this, the concept of transport operation categories (TOCs) and hub operation categories (HOCs) has been introduced by the ISO 14083. They represent "[...] a group of operations sharing similar characteristics, in a defined time period (up to one year), [and] is the key reference point for the calculation of the GHG emissions of a TCE." [ISO 14083, 2023]

Such TOC characteristics encounter e.g., the number and type of vehicles, nature and consistency of the vehicle operations, nature of the freight carried, or any processes associated with maintaining the condition of the freight such as temperature-control. In EcoTransIT World this is realized by the activity units and freight types as outlined in chapter 3.3 as well as the mode-specific TOCs in the chapters 3.7 Output

Transport chains have various impacts on the environment. Based on life cycle analysis and scientific reviews, these environmental categories have been selected for EcoTransIT World, because they are quantifiable and can be used to compare individual transport chains. The selection was made according to following criteria:

- Particular relevance of the impact
- Proportional significance of cargo transports compared to overall impacts
- Data availability
- Methodological suitability for a quantitative comparison of individual transports.

GHG emissions

In accordance with ISO 14083, EcoTransIT World assesses GHG emissions of transport chains, providing both, carbon dioxide (CO_2) emissions as main indicator for the greenhouse effect as well as all GHG emissions expressed in terms of carbon dioxide equivalents (CO_2e).

For all GHG emissions, the latest findings of the Intergovernmental Panel on Climate Change (IPCC) are considered (i.e., currently the 6th Assessment report, see [Smith et al., 2021] as required by ISO 14083: i.e., the list of GHGs and their individual Global Warming Potential (GWP) with a 100-year perspective (not including climate-carbon feedback) are used.

Table 1: GWP100a characterisation factors for the three main GHG

Component	Name	GWP100a
CO_2	Carbon dioxide emissions (fossil)	1.0
CH_4	Methane	27.2
N_2O	Nitrous oxide	273.0

Source: Smith et al., 2021

Note: Since a complete combustion of all fossil carbon in the fuel is already included into the operational CO_2 emissions, we use the factor for biogenic methane.

Air pollutants

In addition to GHG emissions, the following parameters for environmental impacts of transports are covered:

Table 2: Environmental impacts included in EcoTransIT World

Abbr.	Description	Reasons for inclusion
PEC	Primary energy consumption	Main indicator for resource consumption
CO_2	Carbon dioxide emissions	Main indicator for greenhouse effect
CO_2e	Greenhouse gas emissions as CO_2-equivalent	Greenhouse effect
NO_X	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
SO_2	Sulphur dioxide emissions	Acidification, eco-toxicity, human toxicity
NMHC	Non-methane hydrocarbons	Human toxicity, summer smog
Particles	Exhaust particulate matter from vehicles and from energy production and provision (power plants, refineries, sea transport of primary energy carriers), in ETW particles are quantified as PM 10	Human toxicity, summer smog

Particulate Matter (PM) emissions are defined as exhaust emissions from combustion; therefore, PM emissions from abrasion and re-suspension are not included in EcoTransIT World.

External Cost

External costs refer to the economic costs associated with transport activities that are not directly borne by the transport providers or users but are instead imposed on society and the environment. These costs are significant because they encompass various negative impacts of transport, such as environmental degradation and accidents, which are often not reflected in the market prices of transport services.

The external costs considered in EcoTransIT World include several categories:

- **Air Pollution Costs:** These costs arise from the emissions of pollutants that affect air quality and public health. They include costs associated with respiratory diseases, healthcare, and environmental damage.
- **Climate Costs**: These refer to the costs associated with greenhouse gas emissions that contribute to climate change. They encompass the long-term impacts of climate change on ecosystems, human health, and economies.

- **Costs of Well-to-Tank Emissions:** This category includes emissions and pollution generated during the production and distribution of fuels before they are consumed in vehicles. It accounts for both air pollution and greenhouse gas emissions.
- **Accident Costs:** These costs are related to accidents involving transport vehicles, including injuries, fatalities, and property damage. They reflect the societal burden of road safety issues.
- **Noise Costs:** These costs arise from noise pollution generated by transport activities, which can affect the quality of life and health of individuals living near transport routes.

By internalizing external costs, EcoTransIT World aims to provide a clearer understanding of the true economic impact of transport decisions, helping stakeholders make informed choices about transport modes and infrastructure investments.

3.1.2 System boundaries of processes

EcoTransIT World quantifies environmental impacts caused by freight transport via road, rail, air, ocean or inland water as well as the transshipment at logistics hubs. More precisely, this includes emissions directly caused by the **operation of vehicles** and the final energy consumption. The operation of vehicles covers both loaded and empty trips, including diversionary and/or out-of-route distances as well as vehicle start-up and idling.

In addition, all emissions caused by the **provision of energy carriers** (i.e., fuels and electricity) and the energy provision infrastructure, are included. Further details on fuel types and life cycles of energy carriers covered are given in chapter 0.

- EcoTransIT World differentiates between individual process steps and the total sum of final energy consumption, refrigerant leakage, and the associated emissions from vehicles and hubs (= operation; former: tank-to-wheel TTW),
- Upstream energy consumption and upstream emissions (= energy provision production and distribution; former: well-to-tank WTT),
- Total energy consumption and leakage of refrigerants and related total emissions: i.e., sum of operation and upstream emissions (= total; former: well-to-wheel WTW).

ISO 14083 requires the calculation and reporting of GHG emissions of transport chains (or individual transport chain elements) covering operational as well as total GHG emissions and GHG emission intensity, which is provided by EcoTransIT World

Excluded processes
EcoTransIT World does not consider the environmental impact resulting from

- The production and maintenance of vehicles (for relevance see chapter 0)

- The construction and maintenance of transport infrastructure
- Warehousing and (re)packing of freight
- The provision or use of Information and Communication Technology (ICT) equipment and data servers related to transport operations
- Black carbon emissions from transport operations
- Additional resource consumption like administration buildings, etc...

3.1.3 Data source and types

The use of representative, high-quality data is an important prerequisite for a robust/meaningful emission calculation. By considering various parameters and using highly specific and very granular transport operation categories, EcoTransIT World helps users to achieve a good geographical, temporal and technological fit /coverage.

EcoTransIT World enables users to use either their own primary data (= data resulting from a measurement) or secondary data (if no primary data is available). The calculation mainly based on modelled data; however, many of the used model values originally stem from aggregated primary. One example is the calculation of the rail energy demand: primary data from four railway companies over a period of one year was used to derive a function for train energy demand. Road transport mainly relies on a model which is calibrated using primary data for different truck types.

3.1.4 User-specific data sources

User-specific calculations in EcoTransIT World enable users to input customized data for fuel consumption, emissions and reduction factors thereby allowing a tailored assessment of transport-related environmental impacts. This functionality is particularly beneficial for organizations seeking to reflect their individual operational practices in their emission reporting.

In the user-specific calculation, users enter individual values for fuel consumption or emissions for the various modes of transport directly as calculation parameters: e.g. the fuel consumption of a truck in litres per 100 kilometres or the electricity consumption in kWh per MJ. As these user-defined values can deviate from the standard EcoTransIT World methodology and cannot be validated, the results are displayed in a separate area as part of a dual calculation. This clearly distinguishes the results of EcoTransIT World 's standard methodology from the results following the user-specific inputs.

In detail, users can provide well-to-wheel (WTW) or total emission factors for various emission types, such as carbon dioxide equivalents and nitrogen oxides, along with the corresponding units, which may include grammes per megajoule or grammes per tonne-kilometre. Additionally, the system allows for the specification of tank-to-wheel (TTW) or operational fuel consumption values, facilitating a detailed customization process based on actual operational data. Users can also incorporate reduction factors, such as those derived from emission reduction certificates, into their calculations. This capability enables organizations to account for emission reductions achieved through market mechanisms, such as book & claim

Ultimately, the calculations performed within EcoTransIT World are based on the user-defined parameters, which can significantly diverge from standard values. This flexibility not only enhances the accuracy of emissions reporting but also empowers organizations to make informed decisions regarding their sustainability initiatives.

3.2 Modelling approach (bottom-up)

EcoTransIT World is a tool which takes the perspective of a shipper – the owner of freight that needs to be transported – who wants to estimate the emissions associated with a particular transport activity or a set of different transport operations. But the tool may be also used by carriers – the operators and responsible parties for operating vehicles and vessels – to estimate emissions for example for benchmarking purposes. The calculation follows principles of life cycle assessments (LCA) and carbon footprints.

The major rule is that the shipper (freight owner) and carrier are responsible for the vessel`s utilisation, averaged over the entire journey, including the return trip. This rule has been common practice for land-based transports in LCA calculations and is applied also to waterborne and airborne freight. Thus, even if a shipper may fill a tanker to its capacity, he is likewise responsible for the empty return trip which would not have taken place without the loaded trip in the first place. Therefore, a shipper in this case must apply a 50% average load over the entire return trip. This fundamental ecological principle considered by EcoTransIT World is a general requirement according to ISO 14083. The calculation meets the ISO standard only when this roundtrip approach is used.

Similarly, other directional and trade-specific deviations, such as higher emissions from head winds (aviation), sea currents (ocean shipping) and from river currents (inland shipping) are omitted. These effects, which can be both positive and negative depending on the direction of transport, cancel each other out, and the shipper must take responsibility for the average emissions. It is the purpose of EcoTransIT World to provide the possibility of modal comparisons and calculations of transport services consisting of different transport modes. This also requires that all transport modes are equally treated. Thus, average freight utilisation and average emissions without directional deviations are generally considered.

In EcoTransIT World energy and emissions are calculated for transport services of a certain amount of a homogeneous freight (one special freight type) for a transport relation with one or several legs. For each leg one type of transport vessel or vehicle can be selected. These specifications determine all parameters needed for the calculation:

- **Freight type:** Load factor and empty trip factor (can optionally also be user-defined)
- **Vehicle/vessel type:** Payload capacity (mass related), final energy consumption and emission factors.
- **Transport relation:** road type, gradient, country/region specific fuel mix and energy provision emission factors.

For the calculation algorithm it is not relevant whether the freight occupies a part of a vehicle/vessel or one or several vessels. Energy consumption and emissions are always calculated based on the capacity utilisation of the selected freight type and the corresponding specific energy consumption of the vessel. These assumptions avoid the need of different calculation rules for transports with different freight types in the same vehicle, vessel or train. For ferries and aircraft with simultaneous passenger and freight transport (belly freight) allocation rules for the differentiation between passenger and freight transport are necessary. These rules are explained in the related mode-specific chapters. The approaches applied by EcoTransIT World are aligned with ISO 14083 requirements. EcoTransIT World thus always follows a bottom-up approach.

The total energy consumption and emissions of each transport mode are calculated for vehicle usage (operational emissions) and the upstream processes (energy provision emissions). Several calculation steps are necessary:

- Final energy consumption (operational energy consumption) per net tonne-km
- Energy related vehicle emissions per net tonne-km (operational)
- Combustion related vehicle emissions per net tonne-km (operational)
- Energy consumption and fuel emission factors for upstream process per net tonne-km (energy provision)
- Total energy consumption and total emissions per transport (total)

The following subchapters describe the basic calculation rules for each step. For each transport mode the calculation methodology can slightly differ. More information about special calculation rules and the database are given in the mode-specific chapters.

Final energy consumption per net tonne-km (operational)
The principal **calculation rule** for the calculation of final energy consumption is:

$$\boldsymbol{Final\ energy\ consumption}_{\boldsymbol{per\ net\ tonne\ km}}$$
$$= \frac{\boldsymbol{specific\ energy\ consumption}_{\boldsymbol{of\ vehicle\ or\ vessel\ per\ km}}}{\boldsymbol{payload\ capacity}_{\boldsymbol{of\ vehicle\ or\ vessel}} \cdot \boldsymbol{capacity\ utilisation}_{\boldsymbol{of\ vehicle\ or\ vessel}}}$$

The corresponding **formula** is: $$ECF_{tkm,i} = \frac{ECF_{km,i}}{CP \cdot CU}$$

Abbr.	Definition	Unit
$ECF_{tkm,i}$	Final energy consumption (TTW) per net tonne-km (tkm) for each energy carrier	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HFO)	
$ECF_{km,i,}$	Final energy consumption of vehicle or vessel per km; normally depends on mass related capacity utilisation	[MJ/km]
CP	Payload capacity	[tonne]
CU	Capacity utilisation	[%]

Explanations:

- Final energy consumption (operational) is the most important key figure to calculate the total energy consumption and energy related emissions from transport. For the following calculation steps, final energy consumption must be differentiated for each energy carrier, because different sets of emission factors and upstream energy consumption must be considered for each energy carrier.
- Final energy consumption depends on various factors. E.g. final energy consumption per kilometre for trucks also depends on capacity utilisation and thus the denominator of the formula.
- Energy consumption values per tkm combine the steps: calculation of energy consumption on a vehicle, train, vessels or airplanes basis and assignment of energy consumption to one single shipment. In ISO 14083 these steps are described consecutively. Nevertheless, the steps can be done in an integrated manner. To fulfil the requirements of ISO 14083 it is more important that the entire roundtrip including empty running is considered. EcoTransIT World fulfils this requirement without exceptions.
- The formula above refers to a typical case, which is usual for trucks (final energy consumption per vehicle-km). For other modes, the calculation methodology can be slightly different (see explanations in mode-specific chapters). However, for all modes the same relevant parameters (final energy consumption of vehicle/vessel, payload capacity and capacity utilisation) are required.

Energy related emissions per net tonne-km

The basic calculation rule for the calculation of energy related vehicle emissions is:

$$Operational\ vehicle\ emissions_{per\ net\ tonne\ km} = specific\ energy\ consumption_{of\ vehicle\ or\ vessel\ per\ km} \cdot energy\ related\ vehicle\ emission\ factor_{per\ energy\ carrier}$$

The corresponding formula is: $$EMV_{tkm,i} = ECF_{km,i} \cdot EMV_{EC,i}$$

Abbr.	Definition	Unit
$EMV_{tkm,i}$	Vehicle emissions (operational) per net tonne-km for each energy carrier i	[g/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HFO)	
$ECF_{tkm,i}$	Final energy consumption (operational) per net tonne-km for each energy carrier i	[MJ/tkm]
$EMV_{EC,i}$	Energy related vehicle emission factor (operational) for each energy carrier i	[g/MJ]

Explanations:

- The formula is used for all emission components which are directly correlated to final energy consumption (operational CO_2 and SO_2 emissions) and for combustion related emissions of fuel driven trains and vessels. The formula is also used for the calculation of standardized operational energy consumptions in Megajoule [MJ]. In this case, the energy related energy factors are used (e.g. MJ per litre diesel). To fulfil the requirements of ISO 14083 the energy factors of the International Organization for Standardization ISO 14083 are used.
- Based on the ISO the CO_2 equivalents are also calculated by multiplication of the operational energy consumption with energy related CO_2 emission factors plus the corresponding (vehicle and engine type dependant CH_4 and N_2O operational emissions).

Combustion related emissions per net tonne-km (operational air pollutant emissions)

The principal calculation rule for the calculation of operational NO_x, NMHC and particles emissions (so called combustion related emissions) is:

Operational emissions per net tonne-km =
specific emission factor of vehicle or vessel per km /
(payload capacity of vehicle or vessel * capacity utilisation of vehicle or vessel)

The corresponding formula is:

$$EMV_{tkm,i} = \frac{EMV_{km,i}}{CP \cdot CU}$$

Abbr.	Definition	Unit
$EMV_{tkm,i}$	Vehicle emissions consumption (operational) per net tonne-km for each energy carrier i	[g/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HFO)	
$EMV_{km,i,}$	Combustion related vehicle emission factor (operational) of vehicle or vessel per km; normally depends on mass related capacity utilisation	[g/km]
CP	Payload capacity	[tonne]
CU	Capacity utilisation	[%/100]

Explanations:

- The formula is used for vehicle/vessel emissions of truck and aircraft operation.
- For rail and vessel combustion related emission factors are derived from emissions per engine work, not per vehicle-km. Thus, they are expressed as energy related emission factors.

Upstream energy consumption and emissions per net tonne-km (energy provision)

The principal calculation rule for the calculation of vehicle emissions is

Upstream energy consumption or emissions per net tonne-km =
specific energy consumption of vehicle or vessel per net tonne-km
*** energy related upstream energy or emission factor per energy carrier**

The corresponding formulas are:

$$EMU_{tkm,i} = ECF_{km,i} \cdot EMU_{EC,i}$$

$$ECU_{tkm,i} = ECF_{km,i} \cdot ECU_{EC,i}$$

Abbr.	Definition	Unit
$EMU_{tkm,i}$	Upstream emissions for each energy carrier i	[g/tkm]
$ECU_{tkm,i}$	Upstream energy consumption for each energy carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HS)	
$ECF_{tkm,i}$	Final energy consumption (operational) per net tonne-km for each energy carrier i	[MJ/tkm]
$EMU_{EC,i}$	Energy related upstream emission factor for each energy carrier i	[g/MJ]
$ECU_{EC,i}$	Energy related upstream energy consumption for each energy carrier i	[MJ/MJ]

Explanations:

- Formulas for upstream energy consumption and emissions are equal but have different units.
- Formulas are equal for all transport modes; upstream energy consumption and emission factors used in EcoTransIT World are explained in chapter 0.

Total energy consumption and emissions of transport (total)

The principal rule for the calculation of vehicle emissions is

Total energy consumption or emissions per transport =
Transport Distance * mass of freight transported *
(operational energy consumption or vehicle emissions per net tonne-km +
energy provision energy consumption or emissions per net tonne-km)

The corresponding formulas are:

$$EMT_i = D_i \cdot M \cdot \left(EMV_{tkm,i} + EMU_{tkm,i}\right)$$

$$ECT_i = D_i \cdot M \cdot \left(ECF_{tkm,i} + ECU_{tkm,i}\right)$$

Abbr.	Definition	Unit
EMT_i	total emissions of transport	[kg]
ECT_i	total energy consumption of transport	[MJ]
D_i	Distance of transport performed for each energy carrier i	[km]
M	Mass of freight transported	[net tonne]
$EMV_{tkm,i}$	operational Vehicle emissions for each energy carrier i	[g/tkm]
$ECF_{tkm,i}$	operational energy consumption for each energy carrier i	[MJ/tkm]
$EMU_{tkm,i}$	Energy provision (upstream) emission factors for each energy carrier i	[g/tkm]
$ECU_{tkm,i}$	Energy provision (upstream) energy consumption for each energy carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HS)	

Explanations:

- Transport distance is a result of the routing algorithm of EcoTransIT World
- Energy consumption and emissions also depend on routing (e. g. road categories, electrification of railway line, gradient, distance for airplanes). This correlation is not shown as variable index in the formulas due to better readability.
- Mass of freight is either directly given by the client or recalculated from number of TEU (Twenty-foot Equivalent Unit), if TEU is selected as input parameter.
- Using the formula described above for the calculation of energy consumption and total CO_2 equivalent emissions of transport services fulfil the requirements of ISO 14083.

3.3 Activity units and Freight types

Vehicle size, payload capacity and capacity utilisation are the most important parameters for the environmental impact of freight transports, which quantify the relationship between the freight transported and the vehicles/vessels used for the transport. Therefore, EcoTransIT World provides the possibility to adjust these figures for the transport service selected.

Each transport vessel has a maximum load capacity which is defined by the maximum load weight allowed and the maximum volume available. Typical goods where the load weight is the restricting factor are for example coal, ore, oil or some chemical products. Typical products with volume as the limiting factor are vehicle parts, clothes and consumer articles. Volume freight normally has a specific weight on the order of 200 kg/m^3 and below [Van de Reyd and Wouters, 2006]. It is evident that volume goods need more transport vessels and in consequence more wagons for rail transport, more trucks for road transport or more container space for all modes. Therefore, more vehicle weight per tonne of cargo must be transported and more energy will be consumed. At the same time, higher cargo weights on trucks and rail lead to increased fuel consumption.

As an exception, marine vessels behave slightly different regarding cargo weight and fuel burnt. The vessels' final energy consumption and emissions are influenced significantly less by the weight of the cargo in containers due to other more relevant factors, such as physical resistance factors and the uptake of ballast water for safe travelling. Nonetheless the cargo specification is important for intermodal on- and off-carriage as well as for the case where users want to calculate gram per tonne-kilometre performance figures.

3.3.1 Definition of payload capacity

In EcoTransIT World payload capacity is defined as a mass related parameter.

Payload capacity [tonnes] = maximum mass of freight allowed

For marine container vessels capacity is defined in number of TEU (Twenty-foot equivalent unit, i.e. twenty-foot-long containers):

TEU capacity [TEU] = maximum number of containers allowed in TEU

Further information on the payload capacity for the different transport modes can be found in the respective mode-specific chapters.

Containerized Freight EcoTransIT World allows the calculation of energy consumption and emissions for container transports. Emissions of container vessels are calculated based on the number of containers-spaces occupied on the vessel, expressed in "Number of TEUs" (Twenty Foot Equivalent Units). To achieve compatibility with the other modes, the net weight of the cargo in containers is considered as capacity utilisation of containerized transport.

Containers come in different lengths, most common are 20' (= 1 TEU) and 40' containers (= 2 TEU's), but 45', 48' and even 53' containers are used for transport purposes. Special containers, for example for carrying liquids (Flexi-Tank Container) or open containers may differ from those standard weights. The following table lists some empty container weights.

Table 3: Container types, size and empty weight in EcoTransIT World (ETW)

Container Type	Size	Empty Weight
ETW container (default)	20'	1,95 t/TEU
ETW container (default)	40'	3,9 t/FEU
High Cube container	40'	4,0-5,2 t/FEU
Flat container	20'	2,7 t/TEU
Flat container	40'	4,2 t/FEU
Reefer container	40´	4.5 t/FEU

Source: [Hapag Lloyd, n.d.]

By defining the empty weight of a container, a special kind of container type can be modelled, such as high cube containers or flexy tank containers. In this case, the weight of the container will be considered in the emission calculation. However, users need to consider that the empty weight of the container plus the tonnage per container cannot exceed the maximum payload of the corresponding vehicle.

3.3.2 Definition of capacity utilisation

In EcoTransIT World capacity utilisation is defined as the ratio of freight mass transported (including empty trips) to payload capacity. Elements of the definition are:

Table 4: Elements of the definitions of the capacity utilisation

Abbr.	Definition/Formula	Unit
M	Mass of freight	[net tonne]
CP	Payload capacity	[tonnes]
LF_{NC}	Load Factor: mass of weight / payload capacity $LF_{NC} = M / CP$	[net tonnes/tonne capacity]
ET	Empty trip factor: Additional related to loaded distance assigned to the transport. ET = Distance empty / Distance loaded	[km empty/km loaded],

With these definitions' capacity utilisation can be expressed with the following formula:

Abbr.	Definition/Formula	Unit
CU_{NC}	Capacity utilisation = Load factor / (1 + empty trip factor)	
	$CU_{NC} = LF_{NC} / (1+ET)$	

Capacity utilisation for specific cargo types and transport modes

Capacity utilisation is an important parameter for energy and emission calculations. But capacity utilisation is often unknown. Some possible reasons for this include:

- Transport is carried out by a subcontractor, thus data is not available
- Number of empty kilometres, which must be assigned to the transport is not clear or known
- Number of TEU is known but not the payload per TEU (or inverse)

If capacity utilisation is unknown, users can choose from three different cargo types:

- Bulk goods (e.g. coal, ore, oil, fertilizer etc.)
- Average goods: statistically determined average value for all transports of a given carrier in a reference year
- Volume goods (e.g. industrial parts, consumer goods such as furniture, clothes, etc.)

The following table shows some typical load factors for different types of cargo.

Table 5: Load factors for different types of cargo

Type of cargo	Example for cargo	Load factor [net tonnes / capacity tonnes]	Net-gross-relation [net tonnes / gross tonnes]
Bulk	hard coal, ore, oil	100%	0.72
	waste	100%	0.72
	bananas	100%	0.72
Volume	passenger cars	30%	0.44
	vehicle parts	25-80%	0.40-0.68
	seat furniture	50%	0.57
	clothes	20%	0.35

Source: [Knörr and et al, 1999]

Notice: Special transport examples, without empty trips

This information is used to derive typical load factors and empty journey factors for the three categories (bulk goods, average goods, volume). This was easy for average goods, as values from various statistics are available in these cases. It is more difficult for bulk and volume goods:

Bulk (heavy): For bulk goods, at least regarding the actual transport, a full load (in terms of weight) can be assumed. It is more difficult to estimate the length of the additional empty **trips** required. The transport of many types of goods, e.g. coal and ore, requires the return transport of empty wagons or vessels. The transport of other types of goods however allows the loading of other cargo on the return trip. The possibility of taking on new cargo also depends on the type of carrier. Thus, for example an inland navigation vessel is better suited than a train to take on other goods on the return trip after a shipment of coal. In general, however, it can be assumed that the transport of bulk goods necessitates more empty trips than that of volume goods.

Average and Volume (light): For average and volume goods, the load factor regarding the actual transport trip varies sharply. Due to the diversity of goods, a typical value cannot be determined. Therefore, default values must be defined to represent the transport of average and volume goods. For the empty trip factor of average and volume goods it can be assumed that they necessitate fewer empty trips than bulk goods.

The share of additional empty trips depends not only on the cargo specification but also largely on the logistical organisation, the specific characteristics of the carriers and their flexibility. An evaluation and quantification of the technical and logistic characteristics of the transport carriers is not possible. We use the statistical averages for the “average cargo” and estimate an average load factor and the share of empty vehicle-km for bulk and volume goods.

Capacity utilisation of containerised transports

Many shipments transported in containers are light-weight consumer goods[1]. The emissions per TEU-km are assigned to the net-load of the container. Since emissions of container vessels are calculated on a g/TEU-km basis and energy consumption of the vessel only marginally depends on the load of the container, volume and average weight, cargo is responsible for higher emissions on a per tonne-kilometre basis than heavy weight cargo. Three container load classes and an average empty TEU weight are provided as default values (see Table 6).

Average cargo: In accordance with Clean Cargo the net weight of average goods is defined as 10.0 tonnes per TEU [CCWG, 2015]. Cargo is transported in 20’ and 40’

[1] Container vessels’ carrying capacity by weight is usually achieved if all container spaces are used and containers weigh no more than 12 gross tonnes for large container vessels and 15 tonnes gross for small container vessels. Thus, container vessels cannot be fully loaded with only heavy weight containers.

containers in the ratio of approximately 2 to 5, i.e. 2 TEU to 10 TEU[2]. Thus, for each lift[3] an average of 1.7 TEUs is loaded. The average empty weight of a TEU is 1.95 tonnes[4].

Volume cargo: To determine the default volume cargo load of one TEU a convention was used. It is assumed that light weight cargo (volume cargo) tends to be transported in 40' containers. Generally, a maximum load of 90% of the capacity is assumed due to imperfect fit of the cargo in the container. Then the light weight is assumed to be using 50% of the carrying capacity. Thus, a 40' Container filled 45%[5] to its weight carrying capacity is assumed to represent a light-weight cargo container. These results in 6.0 tonnes/TEU and an average empty container weight of 1.9 tonnes.

Heavy weight cargo: The default heavy weight TEU load is derived similarly. Here 90% of the maximum carrying capacity of the containers is assumed to represent the heavy weight cargo. To determine the average heavy weight, the use of 20' and 40' containers for heavy weight cargo need to be determined. Applying the 1.7 ratio 40' to 20' container results in approximately 5x 40' containers and 2x 20' containers or 12 TEUs. In the set of 12 TEUs and 7 containers, a ratio of 3x 40' containers filled with volume weight cargo and 2x 40' containers plus 2x 20' containers filled with heavy weight cargo result in the overall average weight of 10.5 tonnes. The heavy weight containers are then filled with 14.5 tonnes per TEU on average[6] and an average empty container weight of 2.0 tonnes. A theoretical model for container vessel is assumed to be loaded with

- x-number of average loaded containers (20' and 40')
- plus, x-time the mix of 2x 20' plus 2x 40' heavy load and 3x 40' light weight load.

Table 6: Container net-cargo weights for EcoTransIT World cargo categories (net weight)

Light weight cargo	Average cargo	Heavy weight cargo
6 metric tonnes/TEU	10 metric tonnes/TEU	14.5 metric tonnes/TEU

If goods are transported as weight restricted cargo, users should be careful not to overestimate the pay load of the container. Even if a 20' container can carry more than 21 tonnes of cargo, the on-carriage vehicle may not be able to carry that weight. The maximum gross weight of a 20' container of 24 tonnes requires an on-road truck >32 tonnes gross vehicle weight, usually used to pull flat beds. This represents a special transport because only one 20' container could be carried on the flat bed that can carry 2

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2 A ratio of 1.7 was determined by comparing lifts and TEUs handled from port statistics.

3 Lift is an expression from container terminals and describes the number of containers loaded on-board of vessels.

4 Calculated from a mix of 20' and 40' containers.

5 50% of the container weight capacity utilised to a maximum of 90%.

6 Assuming a maximum utilisation by weight of 90%.

TEUs. If containers are further transported by road, it is recommended not to exceed 18 tonnes per TEU for heavy weight cargo.

Capacity utilisation of containerised sea and intermodal transport

For containerized sea transports the basis for calculating emissions is the number of container spaces occupied on a vessel. The second important information then is the net-weight of the cargo carried in one container. The bulk, average and volume goods have been translated into freight loads of one TEU. The net weight of a fully loaded container reaches at maximum 16.1 tonnes per TEU, corresponding to 100% load. In accordance with Clean Cargo, the net weight of average goods is defined at 10.0 tonnes per TEU [CCWG, 2015]. It is assumed that the net weights of volume and bulk goods are 6.0 respectively 14.5 tonnes per TEU. For intermodal transport – the continuing of transport on land-based vehicles in containers – the weight of the container is added to the net weight of the cargo.

Table 7 provides the values used in EcoTransIT World as well as the formula for calculating cargo loads in containers.

Table 7: Weight of TEU for different types of cargo

	Container [tonnes /TEU]	Net weight [tonnes/TEU]	Total weight [tonnes/TEU]
Bulk	2.00	14.50	16.50
Average	1.95	10.00	11.95
Volume	1.90	6.00	7.90

Sources: [CCWG, 2015], assumptions EcoTransIT World

3.4 Routing

The distance and respective route of a freight shipment is a major influencing parameter for emission calculation. However, most users have no insight into the routing or even the distance the freight has travelled. For this reason, EcoTransIT World includes an internal routing algorithm which is based on huge internal GIS data networks. It is not only the distance of the shipment it is especially the routing detail which are used in the energy-based bottom-up approach to identify a most realistic energy consumption. Additionally, EcoTransIT World uses big data in the background to identify stopovers or port-calls within the routing. Furthermore, it is possible to calculate based on a virtual distance or to adjust the distance by a Distance Adjustment Factor (DAF).

3.4.1 Distance based on internal routing

EcoTransIT World calculates the emissions based on routing information. For this reason, a comprehensive routing algorithm is implemented which uses internal GIS-Data for all modes of transport. The routing is based on the shortest feasible distance (SFD) and takes network attributes (as resistances) into account.

These network attributes are, for example, road classes for road routes or canals for sea routes. So, if there is a highway between the origin and the destination, the truck will probably use it on its route, in accordance with EcoTransIT World`s principal "always take the path of least resistance". Technically, a highway has a much lower resistance (EcoTransIT World: factor 1.0) than an urban road (EcoTransIT World: factor 2.5). Therefore, a stretch of highway must be more than five times as long as a city street before the local road is preferred.

In aviation, no routing is used, and the distance is based on the Great Circle Distance (GCD) between the departure and destination airports plus a take-off and landing distance of 95 kilometres.

3.4.2 Virtual Distance

EcoTransIT World can also calculate with a so-called virtual distance. The specification of a virtual distance disables the tool`s internal routing and enables the calculation of the given distance. Virtual distances can be used to integrate primary distance data, but it disables the differentiation of route attributes within the emission calculation (e.g. different fuel consumptions for motorways and urban roads). The virtual distance can be combined with the empty trip factor for road and rail shipments.

3.4.3 Distance Adjustment Factor (DAF)

A distance adjustment factor can be applied if the calculated route does not include any regular detours, for example to avoid tolls, traffic jams or bad weather, or to take planned stopovers into account. The application of a DAF is disabled by default and needs to be specified by the user.

The only exceptions are ocean shipments calculated with Clean Cargo methodology and disabled ais-based routing variant. They contain a DAF of 15 percent by default.

3.4.4 Distance based on primary data

While standard routing is based on the shortest feasible distance, EcoTransIT World can use real data to determine stopovers for air (satellite-based or scheduled) and port calls for sea (ais-based) shipments.

Therefore, trips are identified out of third-party data which reflecting single journeys between two locations. Trips can have different attributes like carrier, flight number, container service name or vessel information. These attributes enable a respective filtering of trips.

Once the trips are identified, a payload-based aggregation of the selected trips (e.g. all trips of a flight number or carrier) are the base of final distance determination.

Aggregation methods

EcoTransIT World provides different parameters to aggregate trips:

- Share of identified trips (default)
- All trips of the defined timeframe are considered in the calculation.
- Single trip identification
- Only a single trip is considered in the calculation.

Transport date appliance

The transport date defines the start date of the time frame for the trip selection. Furthermore, it is possible to specify an aggregation direction (past, future, balanced) to define the selection of different time periods (30 days, 90 days, 180 days or 365 days) based on the start date. Trips will be included into the result when the arrival date is within the time frame. The date of departure has no impact on the trip selection.

If the start date does not match the available third-party data, it will be adjusted automatically.

Table 8: Transport data appliance for third party data

Transport date	Action	Note
not defined or after the available data date	Transport date will be adjusted to the date of the latest available data	Primary data is updated on a quarterly basis
not defined, Clean Cargo activated	Transport date will be adjusted to the date of the latest available data	Primary data is updated on a quarterly basis
is in the future	N/A and an error occur	
is older than available data	N/A and an error occur	Available data available aviation from 01.01.2021, ocean from 01.01.2020
is within available data	Time frame will be applied as defined	Defaults air 180 days, ocean 365 days

3.4.5 Determination of transshipment locations

The so-called transfer point analysis is necessary if a shipment is to be transported from or to a domestic location, such as a zip code or coordinates, by sea vessel, inland waterway, airplane or train. In this case a respective port, airport or train station is needed, where the transshipment takes place. The transfer point analysis principle depends on individual transport modes and is described in the respective sub-chapters.

3.5 Spatial differentiation

EcoTransIT World's global transport calculations require spatial differentiation. These parameters can be country-dependent or apply to international transports. Spatial differentiation may be required due to the following aspects:

- Vehicles or emission classes/model years including a respective default
- Specific biofuel shares
- Regulations regarding fossil or biogenic fuels and electrification
- Emission factors for energy carriers (e.g. due to varying electricity sources)
- Transport infrastructure (e.g. different street types or degree of electrification)
- Topography
- Global regulations, such as emission control areas (ECA)

For geographic differentiations, EcoTransIT World has clustered the world into regions which contain parameters for single countries or clusters. The following list shows for which countries a spatial differentiation exists. Countries which are not listed are summarised in the respective region.

Region 1, Europe:
Albania (AL), Austria (AT), Belarus (BY), Belgium (BE), Bosnia and Herzegovina (BA), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (GR), Hungary (HU), Iceland (IS), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), Montenegro (ME), Netherlands (NL), Norway (NO), Poland (PL). Portugal (PT), Romania (RO), Serbia (RS), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), Switzerland (CH), Turkey (TR), Ukraine (UA), United Kingdom (GB), others (Non-OECD Europe and Eurasia)

Region 2, Central and South America:
Argentina (AR), Bolivia (BO), Brazil (BR), Chile (CL), Colombia (CO), Costa Rica (CR), Cuba (CU), Dominican Republic (DO), Ecuador (EC), El Salvador (SV), Guatemala (GT), Haiti (HT), Honduras (HN), Mexico (MX), Paraguay (PY), Peru (PE), Uruguay (UY), Venezuela (VE), others (non-OECD Americas)

Region 3, North America:
Canada (CA), United States of America (US)

Region 4, Africa:
Algeria (DZ), Angola (AO), Benin (BJ), Cameroon (CM), Congo (CD), Côte d'Ivoire (CI), Egypt (EG), Ethiopia (ET), Ghana (GH), Kenya (KE), Madagascar (MG), Morocco (MA), Mozambique (MZ), Nigeria (NG), Rwanda (RW), Senegal (SN), South Africa (ZA), South Sudan (SS), Sudan (SD), Tanzania (TZ), Tunesia (TN), Uganda (UG), Zambia (ZM), Zimbabwe (ZW), others (AFR)

Region 5, Asia Russia:
Armenia (AM), Azerbaijan (AZ), Bangladesh (BD), Cambodia (KH), China (CN), Georgia (GE), Hong Kong (HK), Indonesia (ID), India (IN), Iran (IR), Iraq (IQ), Israel (IL), Japan (JP), Kazakhstan (KZ), Malaysia (MY), Myanmar (MM), Nepal (NP), North Korea (KP), Pakistan (PK), Philippines (PH), Singapore (SG), South Korea (KR), Sri Lanka (LK), Russia (RU), Taiwan (TW), Thailand (TH), Uzbekistan (ZU), Vietnam (VN)

Region 6, Australia:
Australia (AU), New Zealand (NZ),

Region 7, Middle East:
Bahrain (BH), Jordan (JO), Qatar (QA), Saudi Arabia (SA), Syria (SY),
United Arab. Emirates (AE)

Region 8, others:
World

For road, air, ocean and inland shipping, the fuel type/mix and its corresponding GHG emission factor are always chosen based on the starting point of the journey. Subsequent refuelling along the route is thus not considered. This also applies to electric trucks, which always use the electricity mix of the country where their journey starts regardless of whether the range is big enough to cover the whole trip. For electric trains, the electricity mix always corresponds to the country they are currently in. Further information on spatial differentiations by mode of transport is described in the corresponding sub-chapters.

3.6 Temperature controlled freight

3.6.1 Additional energy demand for cooled transports

Most refrigerated transports today call for an active cooling of the freight during transportation. In general, this results in an additional energy demand. In addition to the energy demand for cooling, the refrigerant type and the leakage rate have a big impact on GHG emissions (see chapter 3.6.3).

Due to the high complexity of cooling transports, only a very rough estimation of the impact was possible in EcoTransIT World. This estimation is partly based on the internationally known ecoinvent database version 3.4 [Weidema et al., 2013].

There are different ways to transport refrigerated goods for different transport modes. Only refrigerated freight transports needing an active cooling will be considered here. Most refrigerated transports on articulated trucks or in rail or sea transport rely on using an intermodal shipping container (reefer) with an active cooling unit. The electricity needed for this cooling unit can either come from a connection to an external power supply or from a clip-on diesel electric generator set (genset). Sometimes electricity is used to cool the compartment while loading or storing; however, this electricity consumption is taken into account as part of the storage processes and not in the actual transportation chain [Kranke et al., 2011].

In EcoTransIT World a 40-foot high cube reefer container with a capacity of 2 TEU is used for articulated trucks with a GCWR of more than 40 t as well as trains. [Weidema et al., 2013] uses a total weight of the FEU reefer of 34 t leading to a maximum payload of 29.5t. However, in Europe containers are generally not allowed to weigh more than 30.5 t, corresponding to a capacity of 26 t. The specifications of the reefer are shown in Table 9.

Table 9: Specifications of the reefer (40' high-cube container)

Parameter	Value
External dimensions	H: 2.896 m / L: 12.192 m / W: 2.438 m
Weight	4100 kg (4480 kg with refrigeration unit)
Maximum gross weight	30500 kg
Maximum payload	26000 kg

Source: External dimensions and empty weight from [Weidema et al., 2013]

The energy demand and the emissions from cooling are calculated based on the average power demand of the reefer. This power demand may vary considerably depending on the operation mode, the insulation, the target temperature and ambient conditions (temperature, solar radiation). The energy demand for cooling may even be higher than for freezing, because a very precise temperature regulation is needed for cooled goods to prevent them from spoiling or over-ripening.

EcoTransIT World uses an average power consumption of 2.7 kW/TEU [Fitzgerald, Warren B. et al., 2011] for the reefer. With this average power consumption, the capacity and the average load, a power demand for the reefer container per kg of refrigerated goods per hour is obtained. The energy demand for cooling/freezing does not depend on the distance travelled but rather on the time needed for the transport. By using the average speed (including breaks), the cooling demand per hour can be assigned to the distance travelled.

The electricity demand of the reefer is fulfilled by connecting a diesel-powered generator set with a power output of approximately 18 kW to the reefer container. Data for this diesel generator set is taken from the mode TREMOD MM [ifeu, 2015]. Two different emission standards are given: Stage IIIA EU (which corresponds to Tier IV in the US and is also valid for Japan and Canada) and an older, non-regulated diesel generator set, which is used for all other countries. The upcoming Stage V EU standard which will be mandatory from 2019 onwards for new engines in the EU is not yet included in EcoTransIT World.

Table 10: Energy demand and emissions from diesel generator sets with 18 kW per kWh [ifeu, 2015]

	Stage IIIA non-road	No emission standard
Diesel demand	240 g/kWh*	262 g/kWh
NMHC	0.6 g/kWh	1.8 g/kWh
NO_x	6.1 g/ kWh	9.8 g/kWh
PM10	0.4 g/kWh	1.4 g/kWh

* Diesel demand taken from ThermoKing [ThermoKing, 2014]

3.6.2 Refrigerant losses of cooled transports

The impact of refrigerant losses on the greenhouse effect depends on their quantity and the type of the used refrigerant. The amount of refrigerant lost is usually determined by measuring how much refrigerant is needed to refill the cooling unit. Even though the quantity is in general comparably low, the contribution to the greenhouse effect can be nevertheless important, because refrigerants have high global warming potentials (GWP). The GWP of most common refrigerant types in transport ranges between 1500 and 4700, i. e. 1 g refrigerant is equivalent to 1500-4700 g CO_2 (see also Table 11).

As there are only few studies on refrigerant losses, the default values provided by EcoTransIT World are subject to high uncertainty. Therefore, it is strongly recommended that users use primary data for the quantity of refrigerant losses and the type of the used refrigerant.

For calculating the default values, we assume based on [Wagner vom Berg et al., 2023] that cooling units lose 1 kg of refrigerant per year. Based on an internal survey among EcoTransIT World users in 09/2023, we furthermore use a mix of R-143a, R-404A and R-452a (one third each) for reefers and a mix of the four refrigerants listed in Table 11 (one fourth each) for integrated cooling units of trucks. The resulting annual GHG emissions have to be assigned to the distance travelled (for trucks using a cooled box) or to the transport performance (TEU-km, for reefers used in different transport modes). To do so, we use the average annual mileage of a German truck of 58414 km/year (for trucks using a cooled box) and 75000 km/year for all cooled transports using a reefer, respectively. Multiplying by the corresponding global warming potentials given in Table 11 results in a total emission factor of 46 g CO_2e/km for trucks using a cooled box and 19 g CO_2e/TEU-km for reefers.

3.6.3 GHG emission factors for refrigerants

GHG emission factors for refrigerants base on Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In case of blends, the relevant emission factors have been calculated basing on IPCC's publication. The following table outlines most common refrigerant types within logistics; emission factors of further refrigerants are provided in the section 10.4.1.

Table 11: GHG emission factors of the most common refrigerant types in transport [Dobers and Jarmer, 2025]

Refrigerant types	[g CO_2e/g]
R-134a	1530
R-404A	4728
R-410A	2256
R-452a	2292

3.7 External costs

3.7.1 Background

Transport causes high external costs (especially uncovered environmental and accident costs), which are economically relevant and should be internalized from an economic point of view, i.e., charged to the polluter. External costs are an important basis for decision-making in transport, e.g., for decisions on the choice of transport mode or for investment decisions on transport infrastructure. At the EU level, external costs are part of the Euro vignette Directive and could in future be more strongly integrated (internalized) in truck toll systems or other traffic charging systems. For this reason, it is important and exciting for players in international freight transport to know what external environmental and accident costs their transport causes.

The following sections explain how external costs are implemented in EcoTransIT World.

3.7.2 External cost rates

The following relevant external cost categories of transport are considered:

- Air Pollution costs
- Climate costs
- Costs of well-to-tank emissions (Air pollution and GHG)
- Accident costs
- Noise costs

The main source for the cost rates is the Handbook on the external costs of transport [EC, 2019][7]. This Handbook presents best practice approaches to estimate different categories of external costs of transport and was last updated in 2019. The comprehensive methodical composition of the cost categories is not discussed here and can be read in the manual. The Handbook considers road transport, rail transport, inland waterway transport (IWT), maritime transport and aviation, which fits perfectly to the transport modes of EcoTransIT World.

The Handbook generally presents the external cost rates in several units (e.g., per tonne, per vehicle kilometre, per person and noise bin, etc.). The appropriate unit for the calculation can be selected accordingly. For the present calculations, cost rates per tonne of emissions are used for air pollutants and GHG, while cost rates per vehicle kilometre are used for accidents and noise. Exceptions are the accident cost rates for IWT, which are provided per tonne and those for maritime, which are provided in costs per port call. The cost rates for aircraft noise are also given per tonne instead of vehicle kilometre.

The EU Handbook on external costs of transport generally differentiates vehicle categories (passenger car, bus, coach, motorcycle, light commercial vehicles, heavy goods vehicles), and for noise even size classes where relevant (e.g. HGV). Accident costs are differentiated by vehicle category and road type (motorway, urban, rural). Thus, cost rates of vehicle categories were selected and aggregated where necessary to match the EcoTransIT World categories as closely as possible. The handbook generally presents cost rates for all EU28 countries, as well as for Switzerland, Norway, USA, Canada, and Japan. This is very beneficial as suitable cost rates can be selected accordingly.

In Table 12 average cost rates for the EU are presented to illustrate the structure and categorisation.

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7 https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-handbook-isbn-978-92-79-96917-1.pdf

3.7.3 Value Transfer

Adjustment of income levels and purchasing power

If the income changes, the willingness to pay for goods also changes. If a data source originates from another country or the data collection dates back several years, the value used must therefore be adjusted to the income level. It should also be noted that the prices of goods are not the same in all countries. In the case of value transfers across national borders, differences in purchasing power must therefore also be corrected. Purchasing power is measured using purchasing power parity (PPP). It measures the factor by which the income in country A must be higher or lower than in country B in order to buy the same bundle of goods. The following formula is used to adjust income levels and purchasing power:

$$W_A = W_S \cdot \left(\frac{Y_A}{Y_S}\right)^e$$

With:

- W_A – Value for the application
- W_S – Value determined in primary study
- Y_A – PPP-weighted per capita income in application
- Y_S – PPP-weighted per capita income in primary study
- e – Income elasticity of willingness to pay (in this case e = 1)

PPP-weighted gross national income per capita is calculated by multiplying the PPP-weighted exchange rate by the gross national income (GNI) per capita. The corresponding data are taken from the database "World Bank World Development Indicators" [World Bank, 2025b].

Price level adjustment (over time)

The price level changes over time. The year in which the Handbook on external cost of transport collected the data is 2016 and expressed in $€_{2016}$. In EcoTransIT World, the base year for monetizing environmental impacts is EcoTransIT 2023. The value of the Handbook has therefore to be adjusted to $€_{2023}$. For this purpose, the GDP deflator [World Bank, 2025a] is used.

The adjustment to the current price level is made using the following formula:

$$W_A = W_S \cdot \left(\frac{D_A}{D_S}\right)$$

With:

- W_A – Value for the application
- W_S – Value determined in primary study (corrected for income level and purchasing power according to previous Chapter)
- D_A – GDP deflator index of the year the application
- D_S – GDP deflator index of the year of the primary study data collection

Table 12: Average external cost rates for the EU for all cost categories in € $_{2016}$

Cost category	Cost type	Unit	EU28
Air pollution	NO_X-cities-TTW	€ per ton	21’300
	NO_X-rural-TTW	€ per ton	12’600
	NMVOC-all areas-TTW	€ per ton	1’200
	SO_2-all areas-TTW	€ per ton	10’900
	PM-exhaust-Metropolitan-TTW	€ per ton	381’000
	PM-exhaust-Urban-TTW	€ per ton	123’000
	PM-exhaust-Rural-TTW	€ per ton	70’000
	PM-nonexhaust-all areas-TTW	€ per ton	22’300
Greenhouse gas	CO_2-eq-all areas Well-to-tank	€ per ton	100
	NO_X-all areas-WTT	€ per ton	10’900
	NMVOC-all areas-WTT	€ per ton	1’200
	SO_2-all areas-WTT	€ per ton	10’900
	PM-exhaust-all areas-WTT	€ per ton	19’400
	PM-nonexhaust-all areas-WTT	€ per ton	22’300
Accidents	Road-Motorway-HGV	€-cent/vkm	1
	Road-Urban-HGV	€-cent/vkm	1
	Road-Rural-HGV	€-cent/vkm	2
	Rail-Average	€-cent/vkm	34
	Aviation-Average	€-cent/vkm	1
	IWT-Average	€ Per tonne	86
	Maritime-Average	€ per port call	318
Noise	Road-HGV Cat 1	€-cent/vkm	4
	Road-HGV Cat 2	€-cent/vkm	6
	Road-HGV Cat 3	€-cent/vkm	6
	Road-HGV Cat 4	€-cent/vkm	7
	Rail-Elec freight train	€-cent/vkm	359
	Rail-Diesel freight train	€-cent/vkm	201
	Aviation-Average	€ per Ton	9

Source: adapted from EU Handbook on external costs of transportation

4 GHG and other emission factors of energy carriers

In addition to operational emissions (also known as tank-to-wheel/ TTW) caused by operating the vehicles, the total emissions (also known as well-to-wheel/ WTW), which include the emissions from energy provision (well-to-tank/ WTT), are considered by EcoTransIT World. Thus, the impact of extraction and provision of the different energy carriers is included. Considering total as well as operational GHG emissions is a requirement of the international standard ISO 14083. EcoTransIT World provides operational as well as total emission data not only for energy consumption and GHG emissions, but also for air pollutants. Therefore, it provides emission data always in the same system boundaries as required by ISO 14083.

The main energy carriers used in freight transport processes are (liquid or gaseous) fossil fuels such as gasoline, diesel, kerosene, (low sulphur) heavy fuel oil and natural gas as well as electricity. Furthermore, liquid and gaseous biomass fuels (called "biofuels" in this report) like biodiesel, ethanol or biomethane are used and often blended with their fossil counterparts. To compare the environmental impacts of transport processes with different energy carriers, the total energy chain has to be considered:

Energy chain of electricity production:

- Exploration and extraction of the primary energy carrier (coal, oil, gas, nuclear etc.) and transport to the power plant
- Conversion within the power plant (including construction and disposal of power stations)
- Energy distribution (transformation and distribution losses)

Energy chain of fuel production:

- Exploration and extraction of primary energy (crude oil) and transport to the refinery
- Conversion within the refinery
- Production and dismantling of energy source infrastructure (e. g. refinery)
- In the case of natural gas: compression (CNG) or cooling and liquefaction (LNG)
- Energy distribution (transport to service station, filling losses)

Since the ISO 14083 distinguishes between European fuel emission factors and North American fuel emission factors, EcoTransIT World factors are grouped into two country groups: North America (US/ Canada) (also used for South America) and Europe (also used for Asia and Africa). Due to lack of data, the European factors are also used for the rest of the world where reliable fuel emission factors are currently missing.

The fuel emission factors included in ISO 14083 are already outdated and thus more recent fuel emission factors are derived for EcoTransIT World, which follow the ISO 14083 methodology.

The main reason for this deviation is the fact that the ISO 14083 factors for liquid fossil fuels in Europe were mainly based on datasets from ecoinvent 3.8 (released in 2021). However, recent studies found that older crude oil production datasets severely underestimated the amount of methane leakages during crude oil production and transport [IEA, 2022; Jackson et al., 2020; Saunois et al., 2020]. The ifeu refinery model include these higher methane emissions for crude oil based on [esu services, 2024], thus, GHG fuel emission factors in EcoTransIT World are higher than in ISO 14083 for most fossil fuels (a similar correction was carried out in ecoinvent version 3.9.1).

EcoTransIT World uses a wide variety of fuel types for the different transport modes and regions covering all relevant fuel types currently in use for goods transportation.

Table 13: Overview of all fuel types in EcoTransIT World by mode and region

Mode	Fuel types	Europe	North America	Rest of World
Road	Gasoline	X	X	(X)
	Diesel	X	X	(X)
	Compressed natural gas (CNG)	X	X	(X)
	Liquefied natural gas (LNG)	X	X	(X)
	Hydrogen (H_2) (e. g. from SMR)	X	X	
	Ethanol	X	X	(X)
	Biodiesel	X	X	(X)
	Hydrotreated vegetable oil (HVO)	X	X	(X)
	Compressed biomethane (CBM)	X	X	(X)
	Liquefied biomethane (LBM)	X		
	Electricity (country-specific)	X	X	X
Rail	Diesel	X	X	(X)
	Biodiesel	X	X	(X)
	HVO	X	X	(X)
	Electricity (country-specific)	X	X	X
Air	Kerosene	X	X	(X)
	HVO	X	X	(X)
Ocean	Heavy fuel oil (HFO) with up to 2.7% sulfur content	X	X	(X)
	Very low sulfur fuel oil (VLSFO) with 0.5% sulfur content	X	X	(X)
	Ultra-low sulfur fuel oil (ULSFO) with 0.1% sulfur content	X	X	(X)
Inland waterways	Diesel	X	X	(X)
	Biodiesel	X	X	(X)
	HVO	X	X	(X)

Hubs	Diesel, biodiesel and blends	X	X	(X)
	Gasoline, ethanol and blends	X	X	(X)
	Propane	X	(X)	X
	CNG	X	X	(X)
	LNG	X	X	(X)
	Hydrogen	X		
	Liquefied Petroleum gas (LPG)	X	X	(X)
	Electricity (country-specific)	X	X	X
	Heat (different sources): natural gas, heating oil, district heating, LPG, geothermal energy, wood chips, wood pellets, steam	X	(X)	X
	Heat (different sources): diesel, biodiesel or blend	X	(X)	X

Note: Energy carries for Europe are also used in Asia, Africa and Rest of World. Energy carries for North America (Canada/ US) are also used for South America.

Note regarding hubs: If energy carriers are not available for a specific region (e.g., Asia, Africa, South America, Rest of World), the conservative approach has been applied.

In addition to the liquid and gaseous fuel types, EcoTransIT World also covers electricity as an energy carrier for road and rail transport as well as for hubs by using country- or region-specific consumption mixes (also called supply mixes) and their emission factors.

Typically, blends of different fuel types are in use, thus, EcoTransIT World also covers typical fuel mixes and specifies average biofuel content for different types of fuel worldwide.

4.1 European emission factors for fossil and biogenic fuels

European fuel emission factors for fossil fuels are based on the ifeu refinery model. This model was used to define the factors for gaseous fossil fuels (CNG and LNG) and different types of low-sulphur fuel oils (VLSFO and ULSFO) as well as diesel, gasoline, heavy fuel oil (HFO) and liquefied petroleum gas (LPG). All fuel emission factors include infrastructure and are fully in line with the ISO 14083 methodology. Further information on the ifeu refinery can be found in Appendix 13.1 as well as in [Fehrenbach, Horst et al., 2018].

The kerosene values are taken from the GLEC Framework v3.1 [Smart Freight Centre, 2024], are aligned with CORSIA and the EU flight label and applied to both North America and the rest of the world. The resulting GHG emission factors of kerosene are lower than the previously used EU values, mainly due to lower energy provision GHG emissions.

European emission factors for fossil fuels

The resulting ISO 14083 compliant fuel properties as well as their GHG emission values are shown in Table 14.

Table 14: Fuel properties and GHG emission factors for fossil fuels and gases for Europe

Fuel type description	Density kg/l	Lower heating value MJ/kg	CO_2e-factor [CO_2e/MJ]		
		operational	operational*	energy provision	total
Gasoline	0.743	42.5	74.99 (74.8 from CO_2)	24.35	99.34
Diesel	0.832	42.8	75.22 (74.1 from CO_2)	22.91	98.13
Compressed natural gas (CNG) (SI truck)	x	49.2	56.04 (55.1 from CO_2)	21.04	77.08
Liquefied natural gas (LNG) (SI truck)	x	49.1	57.32 (56.4 from CO_2)	25.77	83.09
Liquefied natural gas (LNG) (Otto dual fuel sea vessel medium speed)	x	49.1	74.3 (56.4 from CO_2)	25.8	100.0
Kerosene	0.802	43.1	73.9 (73.2 from CO_2)	15.1	89.0
Hydrogen (from SMR)	x	120.0	0	101.3	101.3
Heavy fuel oil (HFO) (2.5% sulphur)	0.970	41.2	76.8 (75.7 from CO_2)	17.1	93.9
Very low sulphur fuel oil (VLSFO) (0.5% sulphur)	0.975	41.3	78.8 (77.7 from CO_2)	20.8	99.6
Ultra-low sulphur fuel oil (ULSFO) (0.1% sulphur)	0.930	41.1	78.6 (77.5 from CO_2)	20.4	99.1
Liquefied Petroleum Gas (LPG)	0.550	45.5	67.0 (66.7 from CO_2)	23.8	90.8

Sources: Kerosene energy provision emissions and lower heating value from [Smart Freight Centre, 2024], all other energy provision emissions as well as lower heating values/ densities and operational CO_2 emissions for VLSFO and ULSFO from ifeu refinery model. Lower heating values, densities and operational CO_2 emissions of all other fossil fuels from ISO 14083.

Note: In addition to the GHG emissions, we also show the (fossil) CO_2 emissions here, since they depend only on the fuel type and not on the operational conditions. The exact GHG emissions vary for different vehicle types in EcoTransIT World.

Operational GHG emissions consist of the (fossil) CO_2 emissions and the non-CO_2 GHG emissions (mainly from methane and nitrous oxide emissions). The non-CO_2 GHG emissions are not only depending on the fuel type, but also on the motor type and aftertreatment system. To calculate the non-CO_2 GHG emissions shown in the table, we used the following typical vehicles types: a petrol-powered light duty vehicle (Euro 6ab), an LPG-powered passenger car (Euro 6), a diesel powered 40t truck (Euro 6a-c), a CNG/ LNG powered 40t truck (SI engine, Euro 5, motorway) as well as an average airplane for kerosene and the value for sea vessels given in GLEC Framework v3.1 [Smart Freight Centre, 2023]. For LNG ships, a methane slip of 3.1 mass-% for an LNG vessel using an Otto motor from Fuel.EU.maritime [Fuel EU maritime, 2021] was used. Table 15 shows the emission factors for energy provision (other than GHG).

Table 15: Emission factors for energy provision of fossil fuels for Europe

Fuel	PEC MJ/MJ	CO_2 g/MJ	NO_x mg/MJ	CH_4 mg/MJ	N_2O mg/MJ	SO_2 mg/MJ	NMHC mg/MJ	PM mg/MJ
Gasoline	0.229	15.0	37.5	288.2	0.41	54.1	150.5	6.35
Diesel	0.269	13.9	35.0	329.2	0.34	44.6	154.4	6.05
CNG	0.138	10.2	23.0	355.8	0.27	10.2	73.8	4.25
LNG	0.222	15.0	28.3	351.0	0.54	16.6	74.9	4.89
H2 SMR	0.390	91.6	52.0	313.0	0.50	23.0	24.0	6.00
HFO	0.158	8.9	38.0	271.6	0.21	27.9	141.4	4.72
VLSFO	0.225	12.5	31.4	273.5	0.25	32.2	132.6	4.85
ULSFO	0.162	12.5	31.2	259.3	0.28	35.5	125.9	4.84
LPG	0.304	14.5	37.3	307.4	0.40	49.9	163.2	6.71

Note: All values are from ifeu calculations. Kerosene can be found in the US table.

European emission factors for biogenic fuels

Biofuels are liquid or gaseous transport fuels made from biomass. Bioethanol (most often made from sugar beet, maize or wheat) can be used to replace petrol; FAME (fatty acid methyl ester) biodiesel or hydrotreated vegetable oil (HVO) (made from different types of vegetable oils) can be used to replace diesel; biomethane (often made from maize, manure or biowaste) can be used to replace natural gas.

Commonly used biofuels are mainly so-called first-generation (or conventionally produced) biofuels made from crop-based inputs, that are grown on land and may compete with a usage as fodder or feed.

In addition, second/third generation (or advanced) biofuels are gaining in importance; today they are produced mainly from waste feedstocks such used cooking oil or biowaste/manure. Residue based (e. g. straw) or non-food crops (e. g. miscanthus) advanced biofuels are still a niche market.

When land is converted from natural land to land where biomass is grown, direct land use change occurs. However, even if a biofuel feedstock is produced on an existing agricultural land, this may displace food or feed crops that have to be grown elsewhere and may lead to an indirect land use change (iLUC) effect. Even though it is understood that iLUC could potentially substantially influence results, it is not commonly included within most legislative or regulatory emission factors / frameworks.

Table 16 presents the EcoTransIT World GHG emission factors together with the lower heating values and densities updated from the previous version using newly available data.

Table 16: GHG emissions factors and fuel properties for biogenic fuels and gases

Fuel type description	Density kg/l	Lower heating value MJ/kg	CO₂e-factor gCO₂e/MJ			Biogenic CO₂ gCO₂/MJ
		operational	operational	energy provision	total	operational
Biodiesel Mix (51.5% rapeseed, 28.6% used cooking oil, 9.6% soybean, 10.4% palm oil)	0.892	37.0	1.12	28.42	29.54	76.3
Biodiesel (rapeseed)	0.892	37.0	1.12	32.66	33.78	76.3
Biodiesel (used cooking oil)	0.892	37.0	1.12	20.85	21.97	76.3
Biodiesel (soy oil)	0.892	37.0	1.12	29.75	30.87	76.3
Ethanol Mix (60.6% maize, 7.1% sugar beet, 32.3% wheat)	0.780	27.0	0.17	27.64	27.81	70.9
Ethanol (maize)	0.780	27.0	0.17	28.48	28.65	70.9
Ethanol (wheat)	0.780	27.0	0.17	28.07	28.24	70.9
Ethanol (sugar beet)	0.780	27.0	0.17	18.49	18.66	70.9
HVO Mix (65% rapeseed, 35% used cooking oil)	0.770	44.0	1.12	20.63	21.75	64.2
HVO (used cooking oil)	0.770	44.0	1.12	15.05	16.17	64.2
HVO (rapeseed)	0.770	44.0	1.12	23.62	24.74	64.2
Bio CNG Mix (48.5% maize, 14.7% manure, 13.5% grass, 12.5% biowaste, 10.8% wheat) (road)	X	50.0	0.9	26.82	27.72	55.0
Bio CNG (maize) (road)	X	50.0	0.9	23.99	24.89	55.0
Bio CNG (manure) (road)	X	50.0	0.9	22.18	23.08	55.0
Bio CNG (biowaste) (road)	X	50.0	0.9	23.89	24.79	55.0
Bio CNG (grass)	X	50.0	0.9	39.92	40.82	55.0
Bio CNG (wheat whole plant)	X	50.0	0.9	32.83	33.73	55.0
Bio LNG Mix (48.5% maize, 14.7% manure, 13.5% grass, 12.5% biowaste, 10.8% wheat) (road)	X	50.0	0.9	30.29	31.19	55.0
Bio LNG (maize) (road)	X	50.0	0.9	27.23	28.13	55.0
Bio LNG (manure) (road)	X	50.0	0.9	25.38	26.28	55.0
Bio LNG (biowaste) (road)	X	50.0	0.9	27.07	27.97	55.0
Bio LNG (grass)	X	50.0	0.9	45.04	45.93	55.0
Bio LNG (wheat whole plant)	X	50.0	0.9	36.04	36.93	55.0

Source: ifeu calculations

Note: Operational non-CO_2 GHG emissions are assumed to be the same as for fossil counterparts (diesel, petrol, CNG/ LNG) and are valid for road transport; operational CO_2 emissions are set to zero. Operational biogenic CO_2 emissions are not included into the overall CO_2 or GHG emissions but given separately.

It is important to note that these emission factors do not account for any iLUC (indirect or induced land use change) to be compatible with the renewable energy directive (RED III). However, all biofuels using a crop-based feedstock may lead to an additional impact from indirect land use change that can (partly) compensate for any possible emission savings[8]. Table 17 summarises the other emission factors for biofuels.

Table 17: Emission factors for energy provision of biofuels

Fuel	PEC MJ/MJ	CO_2 g/MJ	CH_4 mg/MJ	N_2O mg/MJ	SO_2 mg/MJ	NMHC mg/MJ	PM mg/MJ	NO_x mg/MJ
Biodiesel Mix	0.412	20.0	74.28	9.73	51.86	40.53	13.00	91.77
Biodiesel (rapeseed)	0.452	22.6	68.89	16.31	20.41	22.20	5.89	89.73
Biodiesel (UCO)	0.308	15.4	58.97	0.40	62.98	26.86	9.50	81.38
Biodiesel (soybean)	0.565	22.6	82.84	3.97	99.52	42.49	15.28	149.53
HVO Mix*	0.348	17.7	56.80	4.44	52.50	26.10	8.11	92.54
HVO (rapeseed)	0.396	19.8	66.09	6.65	53.81	29.02	9.12	103.23
HVO (UCO)	0.258	13.8	39.54	0.30	50.20	20.69	6.22	72.69
Ethanol Mix	0.300	20.7	85.88	15.84	18.93	20.27	5.35	90.28
Ethanol maize	0.308	21.2	87.23	17.20	23.58	21.28	5.77	93.75
Ethanol wheat	0.304	21.3	87.90	15.31	12.67	19.46	5.72	92.50
Ethanol sugar beet	0.211	14.7	65.17	6.58	7.65	15.33	3.70	50.56
Bio CNG Mix	0.570	17.3	270.03	8.97	45.03	7.82	6.34	57.48
Bio CNG (maize)	0.506	13.8	266.13	10.63	37.34	6.48	4.93	61.32
Bio CNG (manure)	0.231	14.4	270.79	0.65	64.32	9.24	9.38	28.55
Bio CNG (biowaste)	0.256	15.8	283.38	1.42	64.90	13.23	10.88	33.26
Bio CNG (grass)	1.313	32.3	265.29	10.63	37.34	6.48	4.93	61.32
Bio CNG (wheat whole plant)	0.752	19.9	276.98	19.48	39.88	7.27	5.10	102.89
Bio LNG Mix	0.608	19.2	270.97	0.86	77.18	15.35	13.05	39.83
Bio LNG (maize)	1.472	31.7	253.09	10.78	49.90	8.65	7.11	67.99
Bio LNG (manure)	0.909	23.3	264.43	19.62	52.32	9.41	7.20	109.47
Bio LNG (biowaste)	0.412	20.0	74.28	9.73	51.86	40.53	13.00	91.77
Bio LNG (grass)	0.452	22.6	68.89	16.31	20.41	22.20	5.89	89.73
Bio LNG (wheat whole plant)	0.308	15.4	58.97	0.40	62.98	26.86	9.50	81.38

* HVO (or HEFA) can also be used as a marine fuel or a sustainable aviation fuel

Source: ifeu calculations

Further information on the derivation of these emission factors can be found in Appendix 13.2.

[8] Estimates for iLUC factors in RED II lead to an additional impact of +12 g CO_2e/MJ for wheat/ maize, +13 g CO_2e/MJ for sugar beet and +55 g CO_2e/MJ for oilcrops (soybean, rapeseed, palm oil).

4.2 European emission factors for hydrogen

Hydrogen (H_2) is a colourless gas and is seen as one of the cornerstones of a carbon-free economy in the future. It can be used in industrial processes, for heating or as a transportation fuel. Currently, the only commercially available hydrogen vehicles are cars, light duty vehicles and trucks; however, there are also plans to use hydrogen as a ocean vessel fuel or in aircraft in the future.

In the media, in politics, among experts and in the public, hydrogen is often referred to with different colours such as green, yellow, grey, blue and turquoise (see image below for a quick overview of the definitions used here). This chapter intends to explain how these colours are defined, which processes are connected to these colours and how they differ in environmental impacts like carbon footprint, primary energy demand, and others.

Other colours sometimes used are pink and rose and are referring to the use of electricity from nuclear energy for the electrolysis process. However, this route is not considered here. In contrast to our definition, the colour yellow is sometimes also used for hydrogen production using electricity from nuclear power or solar power.

The colours of hydrogen are defined based on the production process and the energy source used for hydrogen production. Here we focus on the colours grey, green, yellow, blue and turquoise which are defined in the following.

4.2.1 Colours of hydrogen

Grey hydrogen is based on fossil hydrocarbon feedstocks. These feedstocks are converted into hydrogen and carbon dioxide by steam reforming, the most common process is methane steam reforming, but other processes exist for the steam reforming of other hydrocarbons like fuel oils. Grey is currently the standard colour of hydrogen produced and sold in the world. Since hydrogen is extracted from hydrocarbons, the remaining carbon is usually emitted as carbon dioxide (in methane steam reforming about 6 kg CO_2 per kg H_2) and usually the thermal energy for the reaction is driven by fossil fuels producing another 5-6 kg CO_2 per kg hydrogen. So, in total, grey hydrogen relates to large carbon dioxide emissions and the processes developed for the other colours of hydrogen are designed to reduce these emissions.

Green hydrogen is produced by electrolysis of water using renewable electricity. About 9 kg of water is needed to produce 1 kg of hydrogen, releasing 8 kg of oxygen as side product. Three main electrolysis techniques exist, namely alkaline electrolysis (AEL), polyelectrolyte membrane electrolysis (PEM) and high temperature electrolysis, of which AEL is the standard technology of today and PEM is the emerging technology with large growth rates. Main advantage of hydrogen from electrolysis is that inherently no CO_2 is emitted during H_2 production, however the use of low carbon electricity is crucial for the overall environmental performance. The term green hydrogen can only be used when 100% of electricity is supplied from renewable sources (e.g. wind, water, solar, geothermal). However, the direct use of green electricity for transportation is, wherever possible, always preferable to the use of hydrogen, due to the higher conversion losses of the hydrogen pathway. Furthermore, green hydrogen can only be claimed if additional renewable energy is directly used to produce this hydrogen.

Yellow hydrogen is produced by electrolysis of water, in the same process as green hydrogen, but by using electricity from the grid, i.e. a mix of renewable and non-renewable electricity. As with green hydrogen, no direct CO_2 emissions occur during hydrogen production but since regular grid electricity is used as energy source, significant greenhouse gas emissions may be created during electricity production.

Blue hydrogen is produced from fossil resources like grey hydrogen but (part of) the carbon dioxide emissions are captured and stored. In case the storage is permanent, the carbon dioxide emissions can be reduced compared to grey hydrogen. However, some pitfalls exist, making blue hydrogen not fully CO_2 neutral, for example:

- Current capture technologies capture only 90% of CO_2 of an exhaust gas stream
- Two separate capture units have to be installed for the process gas and the exhaust gas of thermal energy supply
- Extra energy is needed for CO_2 capture
- CO_2 sequestration is currently not 100% “permanent” due to possible leakages

Blue hydrogen projects are currently being planned or built with several projects in UK, the Netherlands and Sweden (European projects only). However, this product is not yet available on the market.

Turquoise hydrogen is produced by pyrolysis of natural gas, a high-temperature (>1000 °C) process that involves the thermal decomposition of methane (CH_4) without the presence of oxygen. In this process methane is broken down into its constituent elements: hydrogen and solid carbon. By avoiding the combustion of methane, turquoise hydrogen production eliminates carbon dioxide emissions associated with conventional methods. The solid carbon by-product can also find applications in various industries. The pyrolysis technology is in the state of laboratory research, and some demo plants exist. Turquoise hydrogen is currently not available on the market.

4.2.2 Emissions of hydrogen production

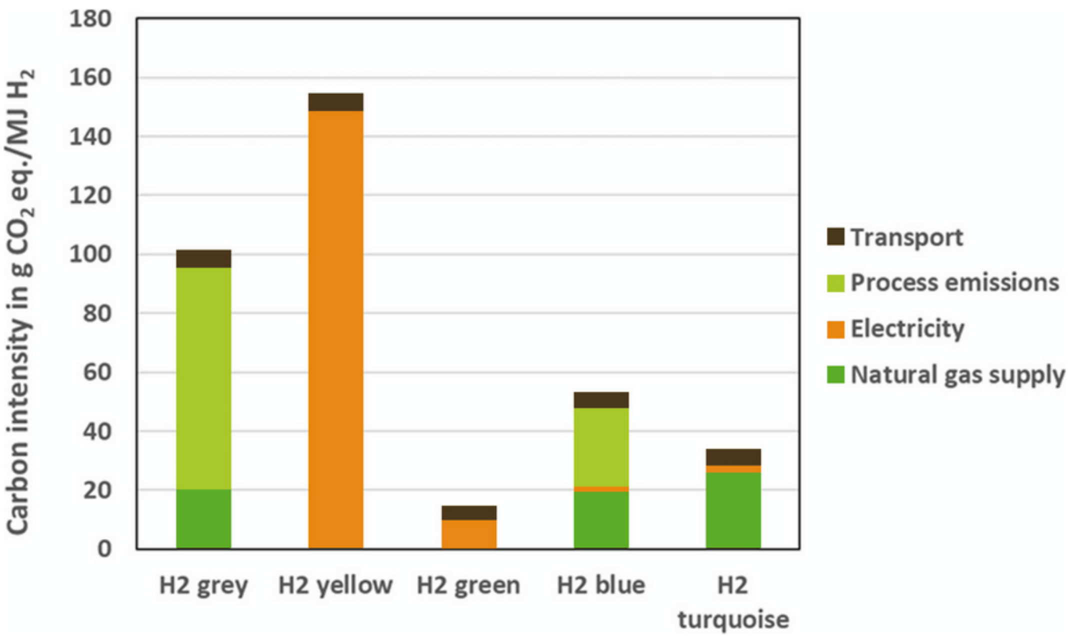
An overview of carbon intensities of the investigated hydrogen pathways is shown in Figure 2 together with a contribution analysis.

Currently available hydrogen production technologies, grey and yellow hydrogen relate to greenhouse gas emissions of about 100 to 150 g CO_2/MJ H_2 mostly caused by the high carbon intensity of methane steam reforming and the current European electricity mix, respectively.

Green hydrogen, produced by electrolysis using only renewable electricity, can be obtained at a carbon intensity around 15 g CO_2/MJ H_2.

Future technologies based on natural gas like blue hydrogen (steam reforming + CCS) or turquoise hydrogen (methane pyrolysis) exhibit significantly higher carbon intensities (33-53 g CO_2/MJ H_2) than green hydrogen, mostly due to the greenhouse gas emissions connected with natural gas extraction and processing (both combustion of natural gas for energy provision and methane losses) and due to incomplete capture of carbon dioxide from methane reforming.

Figure 2: Carbon intensities of the investigated hydrogen production pathways and contribution of different process steps



Notes: transport: compression to 200 bar, truck transport 150 km; process emissions: direct emissions from production process; electricity: emissions from electricity generation (grey, yellow, blue: EU grid mix; green, turquoise: EU renewables mix); natural gas supply: emissions from extraction and transport of natural gas

Since blue and turquoise hydrogen are not yet available on the market, the emissions shown in Table 18 only cover grey, yellow and green hydrogen. These pathways are included in EcoTransIT World. However, due to the low availability of green/yellow hydrogen on the current fuel market, the default hydrogen colour is always grey.

Table 18: Cumulated Energy Demand, Global Warming Potential and selected emissions to air of the investigated hydrogen production pathways

Impact category	unit	H_2 grey	H_2 yellow	H_2 green
Primary energy consumption	MJ / MJ	1.39	3.89	1.81
Global Warming Potential (AR5)	g CO_2e /MJ	101.3	153.8	14.6
Carbon dioxide, fossil [CO_2]	g/ MJ	91.6	136.2	12.8
Methane [CH_4]	mg / MJ	313	500	43
Dinitrogen monoxide [N_2O]	mg / MJ	0.5	8.5	0.6
Particulate matter < 10 nm [PM10]	mg / MJ	6	28	14
Nitrogen oxides [NO_x]	mg / MJ	52	244	39
Sulphur dioxide [SO_2]	mg / MJ	23	372	68

Process data and assumptions for hydrogen production

Process data for Steam Methane Reforming of **grey hydrogen** was taken from [Antonini, C. et al., 2020] using the scenario 'SMR NG, HT'LT' (steam methane reforming of natural gas at high/low temperature). Main Process data is given in Table 19. Natural gas for steam reforming was assumed to be based on the German supply mix for natural gas. After production, hydrogen is compressed to 200 bar and transported by trucks as compressed gas. Electricity supply for process and compression was assumed to be the European supply mix.

Natural gas supply is based on [esu services, 2024] and its contribution to climate change is 596 g CO_2e / Nm^3, including extraction, processing and transport to the customer within Europe. A large share of this impact (about 44%) is caused by methane losses along the supply chain. These methane losses are considered according to the figures published by the IEA methane tracker referring to the year 2021 [IEA, 2022].

Process data for electrolysis of **green/yellow hydrogen** was taken from [Koj, J. et al., 2017] assuming an alkaline electrolysis unit. Main Process data is given in Table 19. Electricity supply was assumed to be a European mix of only renewable electricity for green hydrogen and the average European grid mix for yellow hydrogen. After production, hydrogen is compressed to 200 bar and transported by trucks as compressed gas.

Table 19: Selected data describing the investigated hydrogen production technologies

Process data	unit	H_2 grey	H_2 green/ yellow
Natural Gas input	Nm^3/MJ_{H2}	3.27E-02	-
Electricity input	kWh/MJ_{H2}	1.03E-04	0.411
CO_2 emissions from process	g/MJ_{H2}	74.4	-

The composition of the European electricity supply from grid and the renewable electricity supply mix in Europe in the year 2020 are shown in Table 20 together with the resulting carbon intensity of both electricity mixes as used for hydrogen production.

Table 20: Composition of the electricity mixes used for hydrogen production and resulting carbon intensity

Energy source	Share in electricity supply EU 2020	Share in EU renewables supply mix 2020
Hard coal	6.9%	-
Lignite	8.5%	-
Oil	1.5%	-
Gas	21.3%	-
Nuclear	26.4%	-
Hydropower	11.5%	40.1%
Wind onshore	11.6%	38.3%
Wind offshore	1.6%	5. %
Photovoltaic	4.2%	16.2%
Solar thermal	0.2%	[a]
Geothermal	0.2%	[a]
Biomass	2.9%	[a]
Biogas	1.8%	[a]
Waste	1.4%	[a]
Carbon intensity (GWP100) in g CO_2e/kWh	348.2	21.6

[a] Solar thermal, Geothermal, Biomass, Biogas and Waste were not considered for green hydrogen production as these energy sources are usually not used for the supply of electrolysers.

Source: [Eurostat, 2023]

Since the data for the 2021 electricity mixes were not available in time for the derivation of the hydrogen pathways, for yellow hydrogen the EU mix from 2020 was used. The difference is however very small, thus the results for yellow hydrogen would only change marginally when using the 2021 numbers.

For **hydrogen transport**, it is assumed that hydrogen is compressed from 50 to 200 bar and loaded into a gaseous tube trailer, which currently is the mode of transport used most widely for short transport distances. The electric energy for hydrogen compression is 0.018 MJ_{el}/MJ_{H2}. The assumed transport distance is 150 km. Payload for these kinds of trucks is 0.5 ton at a gross truck weight of 28 tons.

4.3 North American emission factors for fossil and biogenic fuels

North American emission factors for fossil fuels

The fuel emission factors for fossil fuels in North America are taken from the GREET database [Argonne National Laboratory, 2023]. GREET was originally used for the ISO 14083 emission factors but updated here to reflect the GREET version from 2022 (instead of 2021 as in ISO 14083). Furthermore, values for hydrogen from steam methane reforming of natural gas were added based on GREET 2024.The fuel properties, GHG and fossil CO_2 emission values are shown in Table 21.

Table 21: Fuel properties and GHG emission factors for fossil fuels and gases in North America (GREET 2022)

Fuel type description	Density kg/l	Lower heating value MJ/kg	GHG emission factor gCO₂e/MJ		
		operational	operational	energy provision	total
Gasoline	0.749	41.7	74.99 (72.82 from CO_2)	24.35	99.34
Diesel	0.847	42.6	75.22 (74.88 from CO_2)	22.91	98.13
Liquefied Petroleum Gas (LPG)	0.508	46.0	64.73 (64.50 from CO_2)	15.14	79.88
Compressed Natural Gas (CNG) (SI truck)	x	47.1	56.04 (56.23 from CO_2)	21.04	77.08
Liquefied natural gas (LNG) (Otto dual fuel ocean vessel medium speed)	x	48.6	57.32 (56.46 from CO_2)	25.77	83.09
Kerosene	0.802	43.1	73.90 (73.16 from CO_2)	15.10	89.00
Heavy Fuel Oil (HFO) (2.7% sulphur)	0.991	39.5	80.64 (81.97 from CO_2)	14.09	96.06
Very Low Sulphur Fuel Oil (VLSFO) (0.5% sulphur)	0.991	39.5	81.97 (80.64 from CO_2)	15.35	97.32
Ultra-low sulphur fuel oil (ULSFO) (0.1% sulphur)	0.991	39.5	81.97 (80.64 from CO_2)	15.65	97.62
H2 SMR	x	120.1	0	84.73	84.73

Sources: [Argonne National Laboratory, 2023]; Non-CO_2 operational GHG emissions assumed to be the same as for the EU fuels (except CNG SI truck where Non-CO_2 operational emissions are based on the >33,000-80,000lbs (articulated) model year 2017-2020 on motorway), kerosene from GLEC v3.1

The GREET database uses a different methodology to account for the methane emissions from crude oil/ gas extraction. By following a hybrid approach, they give a mixture of the bottom-up methane emissions and the top-down methane emissions. Thus, generally the North American values underestimate the methane emissions, leading to on average lower GHG emission factors then in Europe.

The following table shows the specific factors for the upstream emissions (WTT).

Table 22: Emission factors for energy production of fossil liquid and gaseous fuels (WTT) in North America

Fuel	PEC MJ/MJ	CO_2 g/MJ	NO_x mg/MJ	SO_2 mg/MJ	NMHC mg/MJ	PM mg/MJ
Gasoline	0.249	17.74	22.28	10.00	27.04	2.42
Diesel	0.202	13.75	19.45	8.78	8.22	1.85
Liquefied petroleum gas (LPG)	0.164	10.97	23.68	20.68	12.65	1.45
Compressed natural gas (CNG)	0.179	10.35	44.74	15.66	12.16	1.23
Liquefied natural gas (LNG)	0.216	12.50	27.70	15.34	9.10	1.35
Kerosene	0.225	10.81	26.67	23.75	74.55	3.64
Heavy fuel oil (HFO) (2.7% sulphur)	0.154	11.09	20.55	10.11	6.84	1.95
Very-low sulphur fuel oil (VLSFO) (0.5% sulphur)	0.174	12.23	21.21	10.36	7.06	1.99
Ultra-low sulphur fuel oil (ULSFO) (0.1% sulphur)	0.179	12.51	21.38	10.42	7.12	2.00
Marine diesel oil (MDO) (0.5% sulphur)	0.167	11.84	20.98	10.27	6.99	1.98
Marine gas oil (MGO) (1% sulphur)	0.154	11.09	20.55	10.11	6.84	1.95

Source: [Argonne National Laboratory, 2023]

Note: Kerosene values are an average between the former EU and the former US values (based on GREET 2023).

North American emission factors for biogenic fuels

Previously, emission factors for biogenic fuels in North America were directly taken from the US GREET model. However, the methodology behind GREET is different than the one mandated in ISO 14083 and used for the European fuel emission factors.

A key difference is that the GREET model follows a different allocation approach: unlike the RED method used for the emission factors in Europe, which is based on allocation according to the energy content of co-products, GREET generally uses substitution and thus gives credits. As an analyses by (Fehrenbach et al. 2016) shows, this leads to similar results in many cases but can also result in significant deviations in individual cases. In addition, the GREET model applies a few additional credits specifically for biomethane (referred to as renewable natural gas, RNG, in GREET), which can be described as otherwise avoided burdens (avoidances). These credits are sometimes difficult to understand and may lead to negative GHG emission factors, which are not in line with the ISO 14083 methodology.

Thus, we have adapted the original datasets from GREET to not include any credits for avoided emissions. Table 23 shows the resulting GHG emissions factors (including substitution, e.g. for rapeseed meal) as well as the fuel properties used in EcoTransIT World.

Table 23: Fuel properties and GHG emission factors for fuels and gases in North America adapted from (GREET 2024)

Fuel type description	Density kg/l	Lower heating value MJ/kg	GHG emission factor gCO_2e/MJ			Biogenic CO_2 gCO_2/MJ
		operational	operational	energy provision	total	
Ethanol (mix) (90% maize + 10% sugar cane)	0.789	27.0	0.17	47.18	47.35	71.0
Ethanol (maize)	0.789	27.0	0.17	48.67	48.84	71.0
Ethanol (sorghum)	0.789	27.0	0.17	50.27	50.44	71.0
Ethanol (sugar cane)	0.789	27.0	0.17	33.83	34	71.0
Biodiesel (mix) (75% soja oil + 25% rapeseed)	0.881	37.9	1.12	37.85	38.97	71.2
Biodiesel (rapeseed)	0.881	37.9	1.12	53.37	54.49	71.2
Biodiesel (soy oil)	0.881	37.9	1.12	32.68	33.8	71.2
Biodiesel (UCO)	0.881	37.9	1.12	22.75	23.87	71.2
Biodiesel (palm oil)	0.881	37.9	1.12	35.46	36.58	71.2
Biodiesel (jatropha)	0.881	37.9	1.12	57.14	58.26	71.2
Biodiesel (camelina)	0.881	37.9	1.12	39.24	40.36	71.2
Biodiesel (PFAD)	0.881	37.9	1.12	16.56	17.68	71.2
Biodiesel (tallow)	0.881	37.9	1.12	21.88	23	71.2
HVO (tallow) (also used as mix)	0.779	44.0	1.12	19.16	20.28	71.2
Bio CNG (municipal solid waste) also used as mix	X	47.2	0.9	44.84	45.74	56.3
Bio CNG (manure)	X	47.2	0.9	17.83	18.73	56.3
Bio-CNG (landfill gas)	X	47.2	0.9	16.67	17.57	56.3
Bio CNG (wastewater sludge)	X	47.2	0.9	80.72	81.62	56.3

Sources: ifeu assessment based on GREET 2024; Non-CO_2 operational GHG emissions assumed to be the same as for the EU fuels (except CNG SI truck where non-CO2 operational emissions are based on the >33,000-80,000lbs (articulated) model year 2017-2020 on motorway)

Note: Bio CNG values (also called renewable natural gas, RNG) were adapted to fit the ISO 14083 methodology and do not include any credits for avoided emissions. Biodiesel is also called Biooil in the US.

The following table shows the specific factors for the upstream emissions (WTT).

Table 24 Emission factors for energy production of liquid and gaseous fuels (WTT) in North America

Fuel	PEC MJ/MJ	CO_2 g/MJ	NO_x mg/MJ	SO_2 mg/MJ	NMHC mg/MJ	PM mg/MJ
Ethanol (mix) (90% maize + 10% sugar cane)	0.49	34.35	102.34	23.92	63.07	32.27
Ethanol (maize)	0.52	36.07	85.76	19.82	57.05	15.32
Ethanol (sorghum)	0.54	35.48	93.19	19.62	60.10	15.80
Ethanol (sugar cane)	0.20	18.92	251.58	60.81	117.21	184.77
Biodiesel (mix) (75% soja oil + 25% rapeseed)	0.23	28.73	26.39	8.43	25.65	1.74
Biodiesel (rapeseed)	0.28	36.98	46.37	13.37	43.73	2.56
Biodiesel (soja oil)	0.21	25.97	19.73	6.78	19.63	1.46
Biodiesel (UCO)	0.29	20.23	17.21	4.67	4.63	1.07
Biodiesel (palm oil)	0.27	20.42	82.57	45.19	10.82	6.86
Biodiesel (jatropha)	0.43	29.95	141.33	69.73	99.07	11.77
Biodiesel (camelina)	0.27	20.08	50.89	15.30	36.00	3.67
Biodiesel (PFAD)	0.21	15.67	13.66	8.65	3.77	1.15
Biodiesel (tallow)	0.29	20.08	16.80	5.54	4.68	1.13
HVO (tallow) (also used as mix)	0.25	16.44	15.07	5.18	4.15	1.08
Bio CNG (municipal solid waste), also used as mix	0.61	42.08	25.06	9.94	3.82	2.17
Bio CNG (manure)	0.80	55.15	28.36	11.12	4.56	2.35
Bio-CNG (landfill gas)	0.09	6.13	4.59	3.89	0.72	0.67
Bio CNG (wastewater sludge)	0.46	31.54	17.24	17.24	8.59	3.87

Source: ifeu assessment based on GREET 2024

Further information on the derivation of the US values, a comparison to the original values including credits as well as a short assessment of their comparability to the European values can be found in Annex 13.2.

4.4 Emission factors for electricity

EcoTransIT World includes fully ISO 14083 compliant worldwide electricity mixes. It uses a location-based approach for production mixes which are converted to consumption/ supply mixes using statistics on net electricity imports for different countries. All electricity emission factors always cover the entire process chain.

The emission factors of electricity production depend mainly on the mix of energy carriers used and the efficiency of the production plants and the electricity losses.

The emission values for the national electricity production are calculated using the UMBERTO based "master network". This model has been continuously developed by ifeu since 2001 and can be used to model the impacts of electricity mixes in Germany and other European or non-European countries. The model consists of different power plants and upstream processes. The percentage of electricity from the different plants as well as fuel supply, plant efficiency, exhaust gas treatment and electricity losses are varied for the different regions. Data on the regional electricity mixes (values are shown in 25) stems from EUROSTAT and the International Energy Agency (IEA) and the reference year is 2023. Data from the construction of the power plants and other infrastructure processes is included in the emission factor calculation.

Table 25: Energy split of electricity production in 2023

Region	Ref. year	Source	Fossils	Renewables (incl. biomass)	Nuclear
Africa	2023	IEA	73.7%	25.4%	0.9%
Algeria	2023	IEA	99.2%	0.8%	0.0%
Angola	2023	IEA	24.8%	75.2%	0.0%
Benin	2023	IEA	93.0%	7.0%	0.0%
Cameroon	2023	IEA	22.6%	77.4%	0.0%
Democratic Republic of the Congo	2023	IEA	0.0%	100.0%	0.0%
Côte d'Ivoire	2023	IEA	73.4%	26.6%	0.0%
Egypt	2023	IEA	86.5%	13.5%	0.0%
Ethiopia	2023	IEA	0.0%	100.0%	0.0%
Ghana	2023	IEA	60.0%	40.0%	0.0%
Kenya	2023	IEA	10.0%	90.0%	0.0%
Madagascar	2023	IEA	51.4%	48.6%	0.0%
Morocco	2023	IEA	77.8%	22.2%	0.0%
Mozambique	2023	IEA	15.6%	84.4%	0.0%
Nigeria	2023	IEA	76.1%	23.9%	0.0%
Rwanda	2023	IEA	45.3%	54.7%	0.0%
Senegal	2023	IEA	85.8%	14.2%	0.0%
South Africa	2023	IEA	86.3%	9.8%	3.8%
South Sudan	2023	IEA	96.0%	4.0%	0.0%
Sudan	2023	IEA	18.2%	81.8%	0.0%
United Republic of Tanzania	2023	IEA	72.2%	27.8%	0.0%
Tunisia	2023	IEA	95.8%	4.2%	0.0%
United Arab Emirates	2023	IEA	71.1%	9.1%	19.8%
Uganda	2023	IEA	2.5%	97.5%	0.0%
Zambia	2023	IEA	10.4%	89.6%	0.0%
Zimbabwe	2023	IEA	52.6%	47.4%	0.0%
Armenia	2023	IEA	41.3%	28.2%	30.5%
Azerbaijan	2023	IEA	92.8%	7.2%	0.0%
Bahrain	2023	IEA	99.7%	0.3%	0.0%
Bangladesh	2023	IEA	98.0%	2.0%	0.0%
Cambodia	2023	IEA	57.6%	42.4%	0.0%
China (including Hong Kong)	2023	IEA	63.8%	31.7%	4.5%
Georgia	2023	IEA	22.8%	77.2%	0.0%
Hong Kong	2023	IEA	98.6%	1.4%	0.0%
India	2023	IEA	76.8%	20.8%	2.4%
Indonesia	2023	IEA	83.7%	16.3%	0.0%
Iran	2023	IEA	93.3%	5.1%	1.6%
Iraq	2023	IEA	98.9%	1.1%	0.0%
Israel	2023	IEA	87.9%	12.1%	0.0%
Japan	2023	IEA	66.3%	25.1%	8.6%
Jordan	2023	IEA	76.9%	23.1%	0.0%

Kazakhstan	2023	IEA	86.5%	13.5%	0.0%
Democratic People's Republic of Korea	2023	IEA	35.3%	64.7%	0.0%
Malaysia	2023	IEA	80.1%	19.9%	0.0%
Myanmar	2023	IEA	52.2%	47.8%	0.0%
Nepal	2023	IEA	0.0%	100.0%	0.0%
Pakistan	2023	IEA	50.8%	32.0%	17.2%
Other non-OECD Asia	2023	IEA	38.5%	61.5%	0.0%
Philippines	2023	IEA	77.1%	22.9%	0.0%
Qatar	2023	IEA	96.4%	3.6%	0.0%
Saudi Arabia	2023	IEA	99.3%	0.7%	0.0%
Singapore	2023	IEA	95.9%	4.1%	0.0%
Sri Lanka	2023	IEA	48.6%	51.4%	0.0%
South Korea	2023	IEA	61.7%	8.3%	30.1%
Syrian Arab Republic	2023	IEA	96.3%	3.7%	0.0%
Chinese Taipei	2023	IEA	84.1%	9.5%	6.4%
Thailand	2023	IEA	80.3%	19.7%	0.0%
Uzbekistan	2023	IEA	89.2%	10.8%	0.0%
Viet Nam	2023	IEA	54.1%	45.9%	0.0%
Australia	2023	IEA	64.9%	35.1%	0.0%
New Zealand	2023	IEA	11.8%	88.2%	0.0%
Argentina	2023	IEA	51.8%	41.8%	6.4%
Plurinational State of Bolivia	2023	IEA	68.8%	31.2%	0.0%
Brazil	2023	IEA	8.4%	89.7%	2.0%
Chile	2023	IEA	35.1%	64.9%	0.0%
Colombia	2023	IEA	29.1%	70.9%	0.0%
Costa Rica	2023	IEA	4.8%	95.2%	0.0%
Cuba	2023	IEA	95.8%	4.2%	0.0%
Dominican Republic	2023	IEA	82.8%	17.2%	0.0%
Ecuador	2023	IEA	25.4%	74.6%	0.0%
El Salvador	2023	IEA	37.4%	62.6%	0.0%
Guatemala	2023	IEA	33.7%	66.3%	0.0%
Haiti	2023	IEA	79.1%	20.9%	0.0%
Honduras	2023	IEA	46.7%	53.3%	0.0%
Mexico	2023	IEA	83.1%	13.4%	3.6%
Non-OECD America	2023	IEA	21.9%	76.2%	1.9%
Paraguay	2023	IEA	0.0%	100.0%	0.0%
Peru	2023	IEA	44.1%	55.9%	0.0%
Uruguay	2023	IEA	7.2%	92.8%	0.0%
Bolivarian Republic of Venezuela	2023	IEA	9.3%	90.7%	0.0%
Belarus	2023	IEA	68.5%	3.0%	28.5%
Non-OECD Europe and Eurasia	2023	IEA	60.9%	22.2%	17.0%
Switzerland	2023	IEA	1.9%	64.4%	33.7%
Ukraine	2023	IEA	32.7%	17.3%	49.9%
United Kingdom	2023	IEA	38.3%	47.9%	13.8%
Middle East	2023	IEA	93.6%	3.7%	2.8%
Canada	2023	IEA	18.9%	67.5%	13.6%
United States	2023	IEA	59.0%	22.8%	18.2%
Russian Federation	2023	IEA	62.4%	19.0%	18.7%
World	2023	IEA	59.6%	31.3%	9.1%
Albania	2023	EUROSTAT	0.0%	100.0%	0.0%
Austria	2023	EUROSTAT	15.0%	85.0%	0.0%
Belgium	2023	EUROSTAT	26.2%	34.2%	39.5%
Bosnia	2023	EUROSTAT	55.4%	44.6%	0.0%
Bulgaria	2023	EUROSTAT	34.0%	25.9%	40.1%
Croatia	2023	EUROSTAT	29.3%	70.7%	0.0%
Cyprus	2023	EUROSTAT	78.5%	21.5%	0.0%
Czech Republic	2023	EUROSTAT	44.6%	14.9%	40.4%
Denmark	2023	EUROSTAT	13.0%	87.0%	0.0%
Estonia	2023	EUROSTAT	50.3%	49.7%	0.0%
EU27	2023	EUROSTAT	31.3%	46.2%	22.5%

Finland	2023	EUROSTAT	5.7%	52.4%	41.9%
France	2023	EUROSTAT	8.0%	27.6%	64.5%
Germany	2023	EUROSTAT	44.2%	54.3%	1.4%
Greece	2023	EUROSTAT	49.4%	50.6%	0.0%
Hungary	2023	EUROSTAT	28.3%	27.2%	44.5%
Iceland	2023	EUROSTAT	0.0%	100.0%	0.0%
Ireland	2023	EUROSTAT	54.3%	45.7%	0.0%
Italy	2023	EUROSTAT	55.2%	44.8%	0.0%
Latvia	2023	EUROSTAT	22.0%	78.0%	0.0%
Lithuania	2023	EUROSTAT	18.1%	81.9%	0.0%
Luxembourg	2023	EUROSTAT	9.2%	90.8%	0.0%
Malta	2023	EUROSTAT	86.0%	14.0%	0.0%
Montenegro	2023	EUROSTAT	37.6%	62.4%	0.0%
Netherlands	2023	EUROSTAT	49.3%	47.5%	3.2%
Norway	2023	EUROSTAT	1.2%	98.8%	0.0%
Poland	2023	EUROSTAT	71.2%	28.8%	0.0%
Portugal	2023	EUROSTAT	25.4%	74.6%	0.0%
Romania	2023	EUROSTAT	30.6%	50.4%	19.1%
Serbia	2023	EUROSTAT	63.8%	36.2%	0.0%
Slovakia	2023	EUROSTAT	15.3%	21.9%	62.8%
Slovenia	2023	EUROSTAT	22.8%	41.7%	35.5%
Spain	2023	EUROSTAT	28.1%	52.0%	19.9%
Sweden	2023	EUROSTAT	1.4%	70.2%	28.4%
Turkey	2023	EUROSTAT	56.3%	43.7%	0.0%

Source: [Eurostat, 2025a; IEA, 2023]
Note: Electricity from waste is assumed to be 50% renewable and 50% fossil.

The resulting GHG emission factors for electricity at medium voltage (used in hubs or by electric vehicles) and at the train pantograph (high voltage + pantograph losses) are shown in Table 26.

Table 26: GHG emissions in g CO_2e per kWh of electricity at medium voltage level (including infrastructure) form 2023

Region	Supply mix [gCO_2e per kWh] at medium voltage
Africa	782.8
Albania	70.0
Algeria	733.9
Angola	303.2
Argentina	381.0
Armenia	292.1
Australia	743.3
Austria	186.5
Azerbaijan	559.3
Bahrain	1115.0
Bangladesh	887.4
Belarus	612.8
Belgium	160.9
Benin	1007.1
Bolivarian Republic of Venezuela	130.0
Bosnia	840.4
Brazil	95.6

Bulgaria	467.1
Cambodia	714.5
Cameroon	289.9
Canada	174.1
Chile	332.3
China (including Hong Kong)	745.7
Chinese Taipei	743.9
Colombia	275.2
Costa Rica	69.8
Côte d'Ivoire	616.6
Croatia	325.1
Cuba	1125.1
Cyprus	748.0
Czech Republic	486.0
Democratic People's Republic of Korea	607.8
Democratic Republic of the Congo	17.3
Denmark	121.3
Dominican Republic	845.6
Ecuador	285.8
Egypt	614.6
El Salvador	310.3
Estonia	328.0
Ethiopia	10.5
EU27	294.0
Finland	62.6
France	73.9
Georgia	176.7
Germany	411.5
Ghana	497.2
Greece	443.2
Guatemala	459.9
Haiti	875.2
Honduras	581.3
Hong Kong	915.2
Hungary	319.4
Iceland	28.5
India	1040.4
Indonesia	1036.5
Iran	755.7
Iraq	1650.9
Ireland	295.6
Israel	749.4
Italy	340.8
Japan	569.2
Jordan	704.0
Kazakhstan	938.0
Kenya	191.3
Latvia	223.1

Lithuania	184.3
Luxembourg	299.3
Madagascar	693.9
Malaysia	792.6
Malta	489.0
Mexico	656.1
Middle East	910.1
Montenegro	501.2
Morocco	960.9
Mozambique	155.1
Myanmar	466.3
Nepal	10.2
Netherlands	288.9
New Zealand	130.1
Nigeria	610.5
Non-OECD America	220.2
Non-OECD Europe and Eurasia	667.8
Norway	22.8
Other non-OECD Asia	453.0
Pakistan	525.8
Paraguay	9.8
Peru	300.5
Philippines	1091.0
Plurinational State of Bolivia	463.2
Poland	761.8
Portugal	197.6
Qatar	593.5
Romania	318.4
Russian Federation	638.6
Rwanda	574.8
Saudi Arabia	824.8
Senegal	1021.3
Serbia	830.8
Singapore	562.6
Slovakia	270.9
Slovenia	258.6
South Africa	1109.3
South Korea	567.8
South Sudan	1172.7
Spain	196.1
Sri Lanka	631.6
Sudan	225.9
Sweden	26.9
Switzerland	78.9
Syrian Arab Republic	918.5
Thailand	576.3
Tunisia	741.0
Turkey	545.8

Uganda	51.3
Ukraine	422.6
United Arab Emirates	467.2
United Kingdom	222.4
United Republic of Tanzania	728.1
United States	452.3
Uruguay	97.8
Uzbekistan	815.0
Viet Nam	692.7
World	634.2
Zambia	196.5
Zimbabwe	964.3

Source: ifeu calculations
Note: More emission factors can be found in Appendix 13.3.

For many countries, imported electricity accounts for only a small portion of the electricity demand, thus, the differences between production and consumption/ supply mix are fairly small. However, some countries import large amounts of electricity, which can lower their consumption/ supply mix if imports come from countries with cleaner sources or raise it if imports come from more GHG-intensive ones.

Electricity at medium voltage is used in EcoTransIT World for electric vehicles (charging losses are accounted for in the energy demand per kilometre) and for hubs. Hubs and electric vehicles generally use electricity at medium voltage level. Charging losses for electric vehicles are included into the energy demand of vehicle operation (see chapter 5.3). Electric trains use high voltage electricity, but additional losses in between the grid and the pantograph of the train need to be included. The resulting emission factors including the losses at the train pantograph are shown in Appendix 13.3.

Emission factors for renewable electricity (for dual accounting)

Some companies buy electricity on the market (e. g. green electricity) with different energy mixes and therefore different emission factors. ISO 14083 allows the use of such values on a company level in addition to the location-based mixes (dual-accounting). To ensure consistency, national and company-specific values can`t be combined in the same emission balance, because this would lead to double counting of emissions from the same energy source. If a company uses EcoTransIT World and is applying a market-based electricity mix in addition to the location-based mix, the company is responsible for the quality of the emission values and for fulfilling the requirements of ISO 14083.

Some companies want to include emission factors for entirely renewable electricity in their dual-accounting using a market-based approach. However, the suppliers of these electricity products are often unable to supply the users with ISO14083-compliant electricity emission factors, since they need to include the emissions from energy infrastructure. To help with these user-specific calculations, this paragraph gives typical emission factors for different renewable electricity pathways.

Table 27: Emission factors of renewable electricity in Germany in g per kWh

Type	CO_2e	CO_2	SO_2	NO_x	PM10	NMVOC
Photovoltaic	56.6	52.3	0.06	0.077	0.032	0.005
Wind, onshore	17.7	16.8	0,035	0.037	0.012	0.007
Wind, offshore	9.7	9.2	0.025	0.029	0.007	0.004
Hydropower (river)	2.7	2.5	0.002	0.007	0.002	0.000
Hydropower (pump storage)	24.9	15.9	0.019	0.030	0.033	0.005
Geothermal	166.4	156.3	0.080	0.174	0.012	0.010

Source: Factors for electricity generation from biomass/ biogas vary depending on the feedstock and process and can be found in [Lauf et al., 2023]

The exact emission factors for renewable energy always depend on the full load hours. Thus, solar energy may have a lower emission factor in sun-rich countries (such as Spain) and a higher emission factor in Nordic countries (such as Sweden). Since almost no country worldwide is expanding their hydropower, renewable electricity from new power plants will mainly stem from wind or photovoltaic.

It is also important to consider that in market-based accounting any electricity not covered by a certificate or a guarantee of origin must use the emission factor of the residual grid mix (this is the portion of the local electricity supply that is not covered with Guarantees of Origin or other renewable energy certificates and usually has a higher emission factor than the location-based grid mix does).

4.5 Emission factors for heating energy at hubs

Emission factors for diesel or biodiesel used for heating purposes at hubs are the same as for transport modes and outlined in previous chapters. Emission factors for different heating energy types can be found in internationally accepted life cycle inventory data bases such as ecoinvent or BAFU by the Swiss Federal Office for the Environment. Possible starting points in the ecoinvent database are the modules listed in Table 28.

Table 28: ecoinvent modules for energy heating types

Heating energy type	Example module of ecoinvent data base
Natural gas	Heat production, natural gas, at boiler condensing modulating <100kW
Biogas	Heat production, biomethane, at boiler condensing modulating <100kW
Heating oil	Heat production, light fuel oil, at boiler 100kW, non-modulating
Geothermal energy	Heat production, at heat pump 30kW, allocation exergy
Wood chips	Heat production, hardwood chips from forest, at furnace 50kW
Wood pellets	Heat production, wood pellet, at furnace 300kW
District heating	Combination of Natural gas (see above) and hard coal (heat production, at hard coal industrial furnace 1-10MW)
Steam	Market for heat, from steam, in chemical industry

4.6 Country-specific biofuel shares

GHG emission factors for different transport modes generally depend on the fuel type, its GHG emissions, and the share of low-carbon biofuels in the fuel mix.

Similar as in the case of electricity, EcoTransIT World always includes location-based fuel mixes derived from statistical data on (historical) biofuel shares.

The average share of biofuels in the different countries is expressed as: biofuel share = biofuel/ (fossil fuel +biofuel) (based on energy content).

Data for the European countries was taken from EUROSTAT [Eurostat, 2025b] and is valid for the year 2023. Other data sources may account for slightly different biofuel shares; however, a validation of the Eurostat data from 2020 and the UN data [UN, 2025] from the same year showed a good overall reliability of the data. The UN data from 2022 was used for countries not given in EUROSTAT. It must be noted that the UN database is given in metric tons, requiring us to convert in TJ using default lower calorific values which may lead to slight discrepancies as the lower calorific value of biodiesel depends on the feedstock, which is not detailed in the UN database.

For the countries listed in

Table 29, country-specific biofuel shares are used. The numbers reflect the share of biofuels in energy content in 2023 and can vary from official data on the share of renewable energy sources. The latter is an instrument for reporting in the context of the EU renewable energy directive (RED) and follows a unique calculation rule (including electricity, other alternative fuels and multiple counting factors).

Unfortunately, data from the UN database was only available for the year 2022, which leads to an inconsistency between the two data sources. EcoTransIT World users have however requested the use of the most recent data possible; therefore, 2023 data from Eurostat and 2022 data from the UN database are combined.

For some countries, no data was available from either Eurostat or the UN database. If this was the case, their biofuel share was set to the default value of 0%. These countries are not listed separately in the following tables. The default share was also set to 0% for the following regions: Africa, Other non-OECD Asia, Non-OECD America, Non-OECD Europe and Eurasia, Middle East and World.

Biofuel shares are distinguished between road, rail and domestic navigation. However, data from the Eurostat database showed that many countries use biodiesel solely for their road transport segment.

Table 29: Share of biodiesel in diesel in the different countries (MJ/ MJ)

Country	Reference year	Source	Biodiesel share in road transport	Biodiesel share in rail transport	Biodiesel share in domestic navigation
EU27	2023	EUROSTAT	7.3%	5.4%	0.6%
Albania	2023	EUROSTAT	26.9%		
Austria	2023	EUROSTAT	6.5%	6.3%	
Belgium	2023	EUROSTAT	10.7%		
Bosnia	2023	EUROSTAT			
Bulgaria	2023	EUROSTAT	6.7%		
Croatia	2023	EUROSTAT	0.02%		
Cyprus	2023	EUROSTAT	6.4%		5.2%
Czech Republic	2023	EUROSTAT	4.9%	4.7%	
Denmark	2023	EUROSTAT	5.6%		
Estonia	2023	EUROSTAT	3.5%		
Finland	2023	EUROSTAT	18.6%	4.2%	5.9%
France	2023	EUROSTAT	7.3%	6.4%	2.3%
Germany	2023	EUROSTAT	7.1%	14.2%	
Greece	2022	EUROSTAT	5.2%		
Hungary	2023	EUROSTAT	7.0%		
Iceland	2023	EUROSTAT	1.6%		
Ireland	2023	EUROSTAT	8.5%		
Italy	2023	EUROSTAT	5.4%		0.7%
Latvia	2023	EUROSTAT	0.3%	3.5%	
Lithuania	2023	EUROSTAT	5.8%	6.0%	
Luxembourg	2023	EUROSTAT	9.2%	7.2%	9.1%
Malta	2023	EUROSTAT	8.9%		
Montenegro	2023	EUROSTAT	0.0%		
Netherlands	2023	EUROSTAT	6.6%	6.6%	0.4%
Norway	2023	EUROSTAT	10.2%		
Poland	2023	EUROSTAT	6.7%		
Portugal	2023	EUROSTAT	7.2%		7.2%
Romania	2023	EUROSTAT	4.3%		
Serbia	2023	EUROSTAT	0.0%		
Slovakia	2023	EUROSTAT	6.7%		
Slovenia	2023	EUROSTAT	6.5%		
Spain	2023	EUROSTAT	8.1%		0.3%
Sweden	2023	EUROSTAT	29.1%		
Turkey	2023	EUROSTAT	0.4%		
Argentina	2022	UN data	7.3%		
Australia	2022	UN data	0.01%		
Brazil	2022	UN data	10.3%	9.4%	
Canada	2022	UN data	5.0%		
China (incl. Hong Kong)	2022	UN data	10.1%		
Colombia	2022	UN data	10.5%		

Hong Kong	2022	UN data	10.1%		
India	2023	UN data	3.5%		
Indonesia	2022	UN data	77.4%	12.4%	
Japan	2022	UN data	0.04%		
Malaysia	2022	UN data	11.1%		
New Zealand	2022	UN data	0.01%		
Peru	2022	UN data	4.5%		
Philippines	2022	UN data	2.1%	2.2%	1.2%
South Korea	2022	UN data	3.1%		
Switzerland	2022	UN data	4.0%	4.0%	3.7%
Thailand	2022	UN data	8.6%		
United Kingdom	2022	UN data	5.8%		
United States	2022	UN data	5.2%	5.3%	4.3%
Uruguay	2022	UN data	0.5%		

Note: If no value is given 0% biofuel was reported in the sources. Greece did not report biofuel usage to Eurostat for 2023, therefore, the 2022 values are used.

Source: ifeu calculations based on [Eurostat, 2025b] and [UN, 2025]

In addition to biodiesel, biomethane is also used in transport. Therefore, a biomethane (bio CNG) share was added in EcoTransIT World for all CNG powered road transports.

Only a limited number of European countries use biomethane for transport purposes and all biomethane is being used solely in road transport. Shares of biomethane for the year 2023 were taken from EUROSTAT and are shown in Table 30.

Table 30: Share of bio methane in road transport

Country	Reference year	Source	Bio methane shares
EU 27	2023	EUROSTAT	4.3%
Austria	2023	EUROSTAT	3.3%
Czech Republic	2023	EUROSTAT	0.1%
Estonia	2023	EUROSTAT	28.7%
Finland	2023	EUROSTAT	29.1%
Germany	2023	AG Energiebilanzen	48.0%*
Iceland	2023	EUROSTAT	100.0%
Norway	2023	EUROSTAT	97.8%
Sweden	2023	EUROSTAT	84.0%

Source: ifeu calculations based on [Eurostat, 2025b],

*Value for Germany would be 0 in Eurostat database

Similarly, bioethanol is often blended into petrol. Its shares are shown in Table 31.

Table 31: Share of ethanol in petrol in the different countries (MJ/ MJ)

Country	Reference year	Source	Ethanol shares in road transport
EU27	2023	EUROSTAT	4.9%
Albania	2023	EUROSTAT	
Austria	2023	EUROSTAT	6.1%
Belgium	2023	EUROSTAT	7.5%
Bosnia	2023	EUROSTAT	0.0%
Bulgaria	2023	EUROSTAT	3.9%
Croatia	2023	EUROSTAT	0.03%
Cyprus	2023	EUROSTAT	
Czech Republic	2023	EUROSTAT	3.6%
Denmark	2023	EUROSTAT	6.5%
Estonia	2023	EUROSTAT	1.1%
Finland	2023	EUROSTAT	11.2%
France	2023	EUROSTAT	8.1%
Georgia	2023	EUROSTAT	
Germany	2023	EUROSTAT	4.9%
Greece	2022	EUROSTAT	3.3%
Hungary	2023	EUROSTAT	5.7%
Iceland	2023	EUROSTAT	15.3%
Ireland	2023	EUROSTAT	4.2%
Italy	2023	EUROSTAT	1.0%
Latvia	2023	EUROSTAT	5.6%
Lithuania	2023	EUROSTAT	6.6%
Luxembourg	2023	EUROSTAT	6.1%
Malta	2023	EUROSTAT	
Montenegro	2023	EUROSTAT	
Netherlands	2023	EUROSTAT	6.0%
Norway	2023	EUROSTAT	17.8%
Poland	2023	EUROSTAT	4.5%
Portugal	2023	EUROSTAT	2.1%
Romania	2023	EUROSTAT	9.9%
Serbia	2023	EUROSTAT	
Slovakia	2023	EUROSTAT	6.2%
Slovenia	2023	EUROSTAT	1.9%
Spain	2023	EUROSTAT	2.5%
Sweden	2023	EUROSTAT	9.8%
Turkey	2023	EUROSTAT	1.2%
Argentina	2022	UN data	5.6%
Australia	2022	UN data	0.9%
Brazil	2022	UN data	45.0%
Canada	2022	UN data	5.3%
China (incl. Hong Kong)	2022	UN data	2.3%
Colombia	2022	UN data	3.1%
Ecuador	2022	UN data	1.1%
Ethiopia	2022	UN data	1.1%

Hong Kong	2022	UN data	2.3%
India	2022	UN data	10.0%
Japan	2022	UN data	1.3%
Kazakhstan	2022	UN data	0.1%
New Zealand	2022	UN data	0.1%
Paraguay	2022	UN data	15.6%
Peru	2022	UN data	4.4%
Philippines	2022	UN data	13.4%
Plurinational State of Bolivia	2022	UN data	4.0%
Switzerland	2022	UN data	2.3%
Thailand	2022	UN data	9.4%
United Kingdom	2022	UN data	5.6%
United States	2022	UN data	7.0%
Uruguay	2022	UN data	7.0%
Viet Nam	2022	UN data	0.4%
Zimbabwe	2022	UN data	15.2%

Note: If no value is given 0% biofuel was reported in the sources. Greece did not report biofuel usage to Eurostat for 2023, therefore, the 2022 values are used.

Source: ifeu calculations based on [Eurostat, 2025b] and [UN, 2025]

In aviation, both biofuels and RFNBO (renewable fuels of non-biological origin, also called eFuels or synthetic fuels produced based on hydrogen extracted by means of electrolysis), are considered "'low-carbon aviation fuels" (fuels which save at least 70% of lifecycle emissions) and are termed SAF ("Sustainable aviation fuel"). Currently, HVO is virtually the only fuel used as SAF (see also Table 13). Until 2025, the only countries reporting any SAF use in aviation in 2023 were Norway with a share of 1.1% and France with 0.6%. However, from 2025 onwards, average minimum SAF shares will be mandatory in several countries – mainly the EU countries, in which the ReFuelAviation legislation [EU, 2023] mandates a minimum average share of 2% from 2025 onwards, but also a few additional countries (refer Table 32). In ReFuelAviation as well as most other SAF regulations, the prescribed shares are defined as averages by country and year, and it is the fuel producers and dealers who must ensure they are implemented. Airlines are only prescribed to fuel at least 90% of their annual consumption within the EU and to report their fuel consumption. They are free to "book and claim" – which means that they can buy, and report, any amount or share of SAF or conventional fuel, while the fuel doesn't have to be physically transferred or used in their planes. This means SAF will not be equally used in all flights and may not be available at all airports. It is essentially the same mechanism as for electricity, in which the "location-based" mix of production types (i.e. the mix physically obtained in a location) can deviate from the "market-based" mix (i.e. the mix the consumer paid for). For this reason, EcoTransIT World has not yet implemented the minimum average shares displayed in Table 32. By default, EcoTransIT World still assumes zero SAF shares (except Norway and France) – but users can specify which share they purchased (i.e. the "market-based" share) as an input.

Table 32: SAF quotas by country or country group in 2025. Please note that these quotas are currently not implemented as default shares in EcoTransIT World (see text).

Country	Legislation	Quota type	Unit of share	Share in 2025
All EU countries	ReFuelEU Aviation [EU, 2023]	Minimum average shares	Energy-based	2%
United Kingdom	Renewable Transport Fuel Obligations (Sustainable Aviation Fuel) Order 2024 [UK Government, 2024]		Energy-based	2%
Switzerland	CO_2 ordinance [Fedlex, 2022]		Energy-based	2%
Norway	State Action Plan [Norway, 2020]		Volume-based	1%
Turkey	2022 proposal [IATA, 2022]		not specified	1%

Source: INFRAS

Once statistical data on the implemented SAF shares for the countries becomes available, it will be included in EcoTransIT World as default values.

While biofuel shares are treated like electricity using a location-based approach, it is easier for companies to use their own market-based biofuel shares, since ISO 14083 does not require dual accounting for own biofuel shares, like it does for market-based electricity.

5 Road transport

5.1 Road freight Transport Operation Categories (TOCs)

In general, EcoTransIT World uses very granular road freight transport operation categories. Users can specify their own load factors and empty trips. Furthermore, two types of conditions (ambient and cooled) are available. All GHG activities are differentiated by topography, road type (motorway, regional or urban), engine type and emission class/model year as well as by vehicle weight (empty and loaded), body type and energy consumed. A distinction is also made between European vehicles and North American vehicles. EcoTransIT World covers (international) long-distance transport using trucks as well as regional or local distribution tours using light duty vehicles.

Classification of truck types

Long-distance road transportation is typically performed by truck trains and articulated trucks. Typically, the gross combined weight rating is limited, e.g. to 40 tonnes in most European countries, to 60 tonnes in Sweden and Finland and to 80,000 lbs on most highways in the United States. For feeding or special transports, other truck types are used. In EcoTransIT World, trucks are classified according to their gross vehicle weight rating (GVWR) or gross combined weight rating (GCWR).

European truck size classes in EcoTransIT World (based on the GVWR/GCWR, also used for Japan):

- Truck >3.5-7.5 t (rigid truck)
- Truck >7.5-12 t (rigid truck)
- Truck >12-20 t (rigid truck)
- Truck >20-26 t (rigid truck)
- Truck >26-40 t* (tractor-trailer)
- Truck >40-50 t (tractor-trailer)
- Truck >50-60 t (tractor-trailer)
- Truck >60 t (tractor-trailer)

Note: *40t trucks as tractor-trailer combinations may sometimes have a maximum weight of up to 44 tonnes, when used for intermodal transport, thus EcoTransIT World includes a 44t truck as an additional size class, which is derived from the 40t truck.

North American Truck size classes in EcoTransIT World (based on GVWR/GCWR):

- Truck >8,500-14,000 lbs (single unit)
- Truck >14,000-19,500 lbs (single unit)
- Truck >19,500-33,000 lbs (single unit)

- Truck >19,500-33,000 lbs (articulated)
- Truck >33,000-80,000 lbs (single unit)
- Truck >33,000-80,000 lbs (articulated)
- Truck >33,000-80,000 lbs (articulated, glider)
- Truck >80,000-100,000 lbs (articulated)
- Truck >100,000-130,000 lbs (articulated)

For US trucks with a GVWR above 19,500 lbs (up to 80,000 lbs), there are separate size classes for single unit and articulated trucks. Glider vehicles are trucks build using a new frame and a used engine which does not meet current EPA emission standards. Besides the vehicle size, the emission standard of the vehicle is an important criterion for the emissions of the vehicle. In European transport, different standards (EURO I -EURO VI) are used. The Pre-EURO I-standard is no longer relevant for most transports, and therefore it is not included.

The European emission standards are used in most countries worldwide for emission legislation. Other relevant standards are the US EPA (U.S. Environmental Protection Agency) emission regulations and the Japanese standards. The following table shows the emission standards used in EcoTransIT World. In contrast to the European and the Japanese case, US trucks are not categorized by emission standards, but by model year.

Table 33: Emission standards in EcoTransIT World (EU and Japan)

EU (model year)	Japan
Euro-I (1992)	JP 1994
Euro-II (1996)	JP 1997
Euro-III (2000)	JP 2003
Euro-IV (2005)	JP 2005
Euro-V (2008)	JP 2009
Euro-VI a-c (2013)	JP 2016
Euro-VI d-e (2019)	

Table 34: Emission standards as model years in EcoTransIT World (North America)

North America (model years)
pre 1999
1999-2000
2001-2002
2003-2006
2007-2009
2010-2013
2014-2016
2017-2020
2021-2024

The most widely used truck technology is still the diesel truck. However, alternative fuel types become available and are gaining importance. Thus, EcoTransIT World also includes trucks powered by (natural) gas (compressed natural gas (CNG) or liquefied natural gas (LNG)) as well as battery-electric (BEV) trucks and fuel cell (FCEV) trucks. Table 35 shows the available technologies for the different truck size classes.

Table 35 Available truck technologies for the different size classes in Europe and North America

Region	Truck size	Diesel	LNG	CNG	Gasoline	BEV	FCEV
Europe	3.5-7.5 t (rigid)	X		X		X	X
	7.5-12 t (rigid)	X		X		X	X
	12-20 t (rigid)	X	X	X		X	X
	20-26 t (rigid)	X	X	X		X	
	26-40 t (tractor-trailer)	X	X	X		X	X
	40-50 t (tractor-trailer)	X	X	X			
	50-60 t (tractor-trailer)	X	X	X			
	>60 t (tractor-trailer)	X	X	X			
North America	>8,500-14,000 lbs (single unit)	X			X	X	X
	>14,000-19,500 lbs (single unit)	X			X	X	X
	>19,500-33,000 lbs (single unit)	X			X	X	X
	>19,500-33,000 lbs (articulated)	X				X	X
	>33,000-80,000 lbs (single unit)	X		X	X	X	X
	>33,000-80,000 lbs (articulated)	X		X	X	X	X
	>33,000-80,000 lbs (articulated, glider)	X					
	>80,000-100,000 lbs (articulated)	X					
	>100,000-130,000 lbs (articulated)	X					

Note: CNG/ LNG trucks are always dedicated gas trucks using an SI engine.

Default truck sizes and emission standard

Usually, EcoTransIT World users specify truck size and emission standard. If the truck type is not specified, a default truck size and emission standard is used.

In Europe, the GVWR for most trucks is 40t, which is also the most common truck size in many other countries. Only in Sweden, extra-large trucks with a GVWR of 60t are used more often. However, there is a considerable number of countries where smaller trucks are being more widely used. To address these differences EcoTransIT World uses different default truck sizes per country as shown in Table 36.

The default truck sizes have been derived based on data from Eurostat, the TRACCS database and partially validated by looking at the truck size legislation in the different countries. For non-EU countries, defaults are based on expert judgement complimented by internal data from carriers operating in those regions.

Table 36: Default sizes for trucks by region/ country

Region	Code	Default truck size
Africa	AFR	Truck >20-26t
	ZA	Truck >26-40t
Asia and Pacific	ASP	Truck >12-20t
	CN	Truck >26-40t
	HK	Truck >20-26t
	IN	Truck >26-40t
	JP	Truck >20-26t
	IR	Truck >12-20t
	KR	Truck >12-20t
Australia	AU	Truck >26-40t
Middle east	MIE	Truck >20-26t
Central and South America	CSA	Truck >12-20t
	BR	Truck >26-40t
	CL	Truck >26-40t
	MX	Truck >26-40t
Europe	EUR	Truck >26-40t
	BA	Truck >26-40t
	EU 27 (without SE)	Truck >26-40t
	ME	Truck >26-40t
	SE	Truck >50-60t
	RS	Truck >26-40t
	TR	Truck >26-40t
	CH	Truck >26-40t
	NO	Truck >26-40t
	IS	Truck >26-40t
	IL	Truck >20-26t
North America	US	Truck >33,000-80,000lbs (articulated)
	CA	Truck >33,000-80,000lbs (articulated)
Russia and FSU	RFS	Truck >26-40t
	RU	Truck >26-40t
World	World	Truck >26-40t

Note: An explanation on the different regions and countries can be found in chapter 3.5

Although most countries have adopted the EU or similar emission standards to some degree, emission regulation still differs greatly between different countries and regions. Therefore, each country/ region is assigned its own default emission standard, used when no user specification is provided. EcoTransIT World users can choose newer or older emission standards than the default value.

It must be noted that the sulphur content of the diesel fuel restricts the use of several exhaust gas treatment technologies for newer emission standards [UNEP, 2007]:

- Diesel oxidation catalysts, commonly used for Euro III engines and onwards, work with sulphur levels up to 500 ppm.
- Selective catalytic reduction (SCR) requires a fuel with less than 50 ppm sulphur. SCR is a key technology for vehicles complying with Euro IV and higher.
- Diesel particulate filters need sulphur free fuels (< 15 ppm) and are primarily used in Euro VI vehicles.

The sulphur content of diesel fuel is assumed according to the valid legislation. For Europe, the sulphur content of diesel is below 10 ppm. In several countries this value is much higher, reaching 5000 ppm or even 8000 ppm in Iran.

The sulphur content of the fuel is also used to calculate the operational SO_2 emissions.

All EU countries are assigned EURO VI as the default emission standard, since vehicles using this standard are already widely adopted in the European market. For all other countries we assume comparable regional standards (available on the market since 2008) or at least EURO II (see Table 37).

Table 37: Sulphur content of diesel and default emission standards for trucks by region/ country

Region	Code	Sulphur content	Default emission standard	Current emission standard
Africa	AFR	5000	EURO II	-
	ZA	500	EURO II	-
Asia and Pacific	ASP	5000	EURO II	-
	CN	50	EURO V	EURO VI
	HK	10	EURO IV	EURO V
	IN	350	EURO II	EURO VI
	JP	10	JP 2009	JP 2016
	IR	8000	EURO II	-
	KR	50	EURO IV	EURO VI
Australia	AU	10	EURO V	EURO V
Middle East	MIE	5000	EURO II	-
Central and South America	CSA	5000	EURO II	-
	BR	500	EURO III	EURO VI
	CL	15	EURO III	EURO V
	MX	500	EURO III	EURO VI
Europe	EUR	500	EURO II	-
	BA	350	EURO II	-
	EU 28	10	EURO VI a-c	EURO VI d-e

	ME	10	EURO II	-
	RS	10	EURO III	EURO III
	TR	10	EURO IV	EURO VI
	CH	10	EURO VI a-c	EURO VI d-e
	NO	10	EURO VI a-c	EURO VI d-e
	IS	10	EURO VI a-c	EURO VI d-e
	IL	10	EURO V	EURO V
North America	CA	15	model years 2021-2023	*
	US	15	model years 2021-2023	*
Russia and FSU	FSU 15	500	EURO II	-
	RU	50	EURO III	EURO V
World	WRLD	5000	EURO II	-

Sources: [ICCT, 2018]; [UNEP, 2007] ; [integer.com, 2016]; [transportpolicy.net, 2016]; [energy.gov.il, 2016]; [trend news agency, 2013]

Note: CN: nation-wide sulphur values; some regions have lower limit values. US, CA: several legislations in place, California has its own standards

Light duty vehicles

Besides trucks, EcoTransIT World users can also calculate emissions of light commercial vehicles (LCV) and passenger cars. The data source used is the "Handbook emission factors for road transport" (HBEFA) [INFRAS, 2023] version 4.2. The following vehicle types are included:

Table 38: Light commercial vehicles and passenger cars

Size	Fuel type	Emission class
LCV N1-I	Gasoline	Euro 1
LCV N1-II	Diesel	Euro 2
LCV N1-III	Battery-electric	Euro 3
Passenger car		Euro 4
		Euro 5
		Euro 6ab
		Euro 6d

Note: For LCV and passenger cars, the emission factors are given on a vehicle-kilometre basis and do not depend on the vehicle load. EcoTransIT World does not include any vehicles using two different fuel types simultaneously.

To date, EcoTransIT World does not include specific values for light commercial vehicles or passenger cars in the US or Canada. Thus, the emission factors given are representative for European conditions only.

5.2 Road freight transport activity

5.2.1 Road distance calculation

The determination of a truck route is based on the EcoTransIT World internal routing (compare chapter 3.4.1) which considers different street categories, such as motorway, country road and urban streets. Depending on the street categories in the data source (OpenStreetMap) the streets have various routing resistance factors in the internal routing algorithm.

Table 39: Resistance of street categories

Street Type	Street category	Resistance	Classification
Motorway, Trunk	0	1.0	Motorway
Primary	1	1.3	Highway
Residential Road	2	1.5	Highway
Secondary	3	1.67	Highway
Tertiary	5	3.33	Highway
Unclassified, other	4	2.5	Highway

In addition, there are ferry routes within the street network. These ferry routes work like virtual roads where the whole truck is placed on the ferry. EcoTransIT World has built in various resistances for ferry routes which can be defined within the calculation parameters.

Table 40: Resistance for ferries in the road network

Ferry handling category	Resistance
Preferred	1
Normal (default)	5
Avoid	100
Deny	∞

5.2.2 Road freight types (payload and utilization)

Payload capacity for trucks

Table 41: Empty weight and payload capacity of different basic truck types

Geography/ Fuel type	Vehicle size	Empty weight [tonnes]	Payload capacity [tonnes]	Permissible total weight [tonnes]
EU (Diesel/ CNG/ LNG)	3.5-7.5 t (rigid)	4	3.5	7.5
	7.5-12 t (rigid)	6	6	12
	12-20 t (rigid)	9	11	20
	20-26 t (rigid)	11	15	26
	26-40 t (tractor-trailer)	14	26 (30)	40 (44)
	40-50 t (tractor-trailer)	16.8	33.2	50
	50-60 t (tractor-trailer)	20	40	60
	> 60 t (tractor-trailer)	25	65	90
EU (electric/ fuel cell)	3.5-7.5 t (rigid)	4	3.5	7.5
	7.5-12 t (rigid)	6.5	5.5	12
	12-20 t (rigid)	10.5	9.5	20
	20-26 t (rigid)	13.3	12.7	26
	26-40 t (tractor-trailer)	17	23	40
US (Diesel/ petrol/ CNG**)**	>8,500-14,000 lbs (single unit)	4	2.4	6.4
	>14,000-19,500 lbs (single unit)	4.9	4.0	8.9
	>19,500-33,000 lbs (single unit)	6.6	8.4	15
	>19,500-33,000 lbs (articulated)	6.6	8.4	15
	>33,000-80,000 lbs (single unit)	11.8	24.5	36.3
	>33,000-80,000 lbs (articulated)	11.8	24.5	36.3
	>80,000-100,000 lbs (articulated)	14.8	30.6	45.4
	>100,000-130,000 lbs (articulated)	18.6	40.4	59.0
US (electric/ fuel cell)	>8,500-14,000 lbs (single unit)	4.0	2.4	6.4
	>14,000-19,500 lbs (single unit)	5.0	3.9	8.9
	>19,500-33,000 lbs (single unit)	8.1	6.9	15.0
	>19,500-33,000 lbs (articulated)	8.1	6.9	15.0
	>33,000-80,000 lbs (single unit)	14.8	21.5	36.3
	>33,000-80,000 lbs (articulated)	14.8	21.5	36.3

Source: Internal analyses (ifeu, IVE)

Note: Weights in this table are based on a curtain sider. Specific truck weights may differ for user-defined truck weights or for other truck body types (e.g. used in containerised and cooled transport). Japanese trucks are assumed to have the same weight as the European trucks.

The payload capacity of a truck is limited by the permissible total weight. Thus, the payload capacity is the difference between the permissible total weight and the empty weight of the truck (including equipment, fuel, driver, container etc.). EcoTransIT World categories trucks into different total weight classes. For each class an average value for empty weight and payload capacity is defined. The following Table 42 shows key figures for empty weight and payload capacity of different truck types used in EcoTransIT World.

In addition to the standard truck types listed in the table above, EcoTransIT World offers other truck body types with different empty weights.

Table 42: Empty weight of different truck body types in tonnes

Geography Fuel type	Vehicle size	Curtain sider	Cargo box	Cooled box	Container TEU	Container FEU	Tank	Car
EU (Diesel/ CNG/ LNG)	3.5-7.5 t (rigid)	4	4.7	5.5				
	7.5-12 t (rigid)	6	6.7	7.5				
	12-20 t (rigid)	9	9.5	11.0			10.3	12.3
	20-26 t (rigid)	11	12.6	13.0	12.5			
	26-40 t (tractor-trailer)	14	15.7	16.0	11.0	13.5	16.0	
	40-50 t (tractor-trailer)	16.8	17.0	18.0	13.8	14.5		
	50-60 t (tractor-trailer)	20	22.0	23.0	17.0	19.5		
	> 60 t (tractor-trailer)	25	26.5	28.0	22.0	23.5		
EU (electric/ fuel cell)	3.5-7.5 t (rigid)	4	4.7					
	7.5-12 t (rigid)	6.5	7.2					
	12-20 t (rigid)	10.5	11.0				12.0	14.2
	26-40 t (tractor-trailer)	17	17.2		14.0	15.0		
US (Diesel/ petrol/ CNG)	>8,500-14,000 lbs (single unit)	4	4.6	5.3				
	>14,000-19,500 lbs (single unit)	4.9	5.6	6.7				
	>19,500-33,000 lbs (single unit)	6.6	7.0	8.5				
	>19,500-33,000 lbs (articulated)	6.6	7.0	8.5				
	>33,000-80,000 lbs (single unit)	11.8	12.4	13.4	11.0	13.5		
	>33,000-80,000 lbs (articulated)	11.8	12.4	13.4	11.0	13.5		
	>80,000-100,000 lbs (articulated)	14.8	16.6	17.8	11.6	14.3	16.9	
	>100,000-130,000 lbs (articulated)	18.6	20.5		15.8	18.1		
US (electric)	>8,500-14,000 lbs (single unit)	4.0	4.6					
	>14,000-19,500 lbs (single unit)	5.0	5.8					
	>19,500-33,000 lbs (single unit)	8.1	8.5					
	>33,000-80,000 lbs (articulated)	14.8	15.4		14.0	16.5		

Source: Internal analyses (IVE)

Capacity utilisation of road transport for different cargo types

Typically, bulk transports are fully loaded transports, in which the permissible total weight is fully utilised, but the return trip is often empty, leading to a higher empty trip factor. For volume goods, the average load factor is fairly low, since they are limited by the available space and not by the vehicle weight.

Reliable data for average load factors and empty trip factors is scarce, thus EcoTransIT World pre-defines these values based on expert judgement. EcoTransIT World users are encouraged to adjust these values if they have more reliable factors for their own transport chains. The average load factor for long distance road transport with heavy trucks in Germany was about 55% in 2013 [KBA, 2013] and 58% in 2001 [KBA, 2001]. These values also include empty vehicle-km. The share of additional empty vehicle-km in road traffic was about 11% in 2013 and 17% in 2001). The average load for all trips (loaded and empty) was about 50% in 2013 and 2001. The share of empty vehicle-km in France was similar to Germany in 1996 [Kienzler, H. P., 1998]. All assumptions and default average values used in EcoTransIT World are summarized in Table 43.

Table 43: Capacity utilisation of road transport for different types of cargo (based on estimations)

	Load factor LF_{NC}	Empty trip factor ET	Capacity utilisation CU_{NC}
Bulk	100%	60%	63%
Average	60%	20%	50%
Volume	30%	10%	27%

Source: Expert judgment based on [KBA, 2001, 2013; Kienzler, H. P., 1998]

Load factor calculation by truck load (FTL/ FCL/ LTL/ LCL/ Auto)

In the case of full truck load (FTL) transport or full container load (FCL) transport, the load factor is determined based on the ratio of loaded cargo to the maximum capacity of the truck. In the container sector, the maximum capacity is reduced by the tare weight of the container(s). For example, a 40-tonne truck (maximum capacity of 26 tonnes) loaded with 13 tonnes of freight has a load factor of 50% for FTL.

Less-than-truckload (LTL) shipping requires a default load factor. A value of 45% is assumed here.

The load factor of average goods (60%) is the calculation basis, if no specifications are made for the load type.

$$Load\ factor_{FTL\ Truck} = \frac{Gross\ freight\ weight}{Maximum\ payload\ of\ the\ truck}$$

$$Load\ factor_{FTL,40t\ Truck} = \frac{13\ t}{26\ t} = 50\ \%$$

Example calculations with different container equipment's for FCL trucks:

$$\boldsymbol{Load\ factor_{FCL,40t\ Truck}} = \frac{\mathbf{10}\boldsymbol{t/TEU\ x}\ \mathbf{2\ TEU}}{\mathbf{40t - 14\ t - 2x1.95\ t}} = \mathbf{90,5\ \%}$$

$$\boldsymbol{Load\ factor_{FCL,40t\ Truck}} = \frac{\mathbf{10}\boldsymbol{t/TEU\ x}\ \mathbf{1\ TEU}}{\mathbf{40t - 14\ t - 1x1.95\ t}} = \mathbf{41,6\ \%}$$

$$\boldsymbol{Load\ factor_{FCL,40t\ Truck}} = \frac{\mathbf{15}\boldsymbol{t/FEU\ x}\ \mathbf{1\ FEU}}{\mathbf{40t - 14\ t - 1x3.9\ t}} = \mathbf{67,9\ \%}$$

Alternatively, EcoTransIT World offers an automatic truck load setting (Auto) that assigns shipments within a given freight weight range to FTL mode, using load factors between 50% and 100%. The other transports are treated as LTL transports with a default load factor of 45%. The users can adjust the FTL/LTL range and the LTL default by defining the corresponding parameters.

5.3 Road freight GHG activities

5.3.1 Energy demand (road)

EcoTransIT World uses an energy-based bottom-up modelling approach, thus the starting point for any GHG calculation is always the energy consumption of the vehicle. Carbon dioxide emissions are calculated by multiplying the energy demand with the corresponding emission factor of the fuel used. In addition, operational methane and nitrous oxide emissions are modelled and added to calculate the operational GHG emissions.

Energy demand of European trucks

EcoTransIT World uses the latest Handbook of Emission Factors for Road Transport (HBEFA) [INFRAS, 2023] for energy consumption as well as operational emissions of diesel, LNG, CNG and fuel cell electric (FCEV) trucks.

Energy consumption of trucks not only depends on the vehicle size and powertrain, but also on the driving conditions and the vehicle load. The load factor impact is also modelled according to the Handbook of Emission Factors [INFRAS, 2023]. Based on that, the fuel consumption of an empty vehicle can be one third below the fuel consumption of a fully loaded vehicle. This impact can be even stronger depending on driving characteristics and the gradient.

The energy consumption per kilometre of a vehicle increases as the load weight becomes heavier. Thus, it is a function of the capacity utilisation.

The energy consumption per kilometre can be calculated as follows:

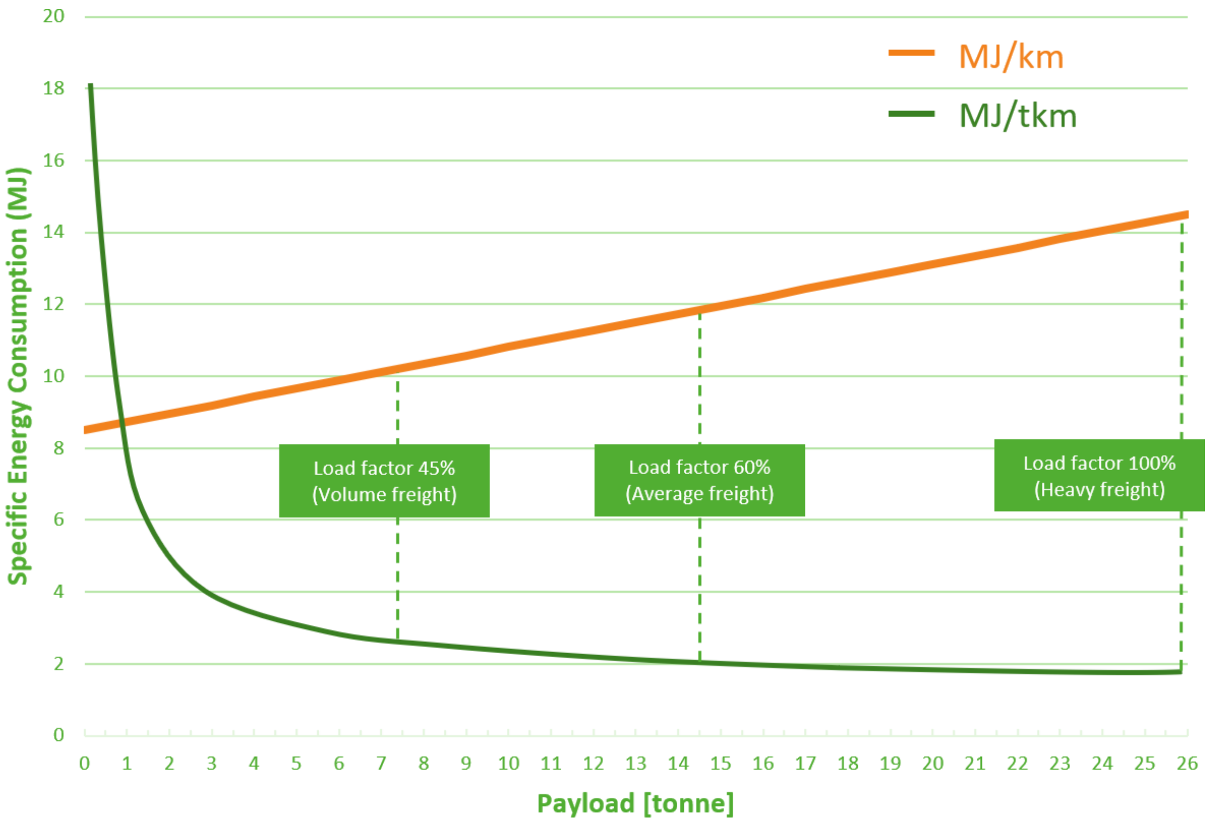
$$ECF = ECF_{empty} + (ECF_{full} - ECF_{empty}) * CU$$

using the following parameters:

- ECF = final energy consumption with actual load (MJ/km)
- ECFempty = Final energy consumption without load (MJ/km) (at CU = 0%)
- ECFfull = final energy consumption with full load (MJ/km) (at CU = 100%)
- M = mass of freight (t)
- CP = payload capacity (t)
- CU = M/CP (capacity utilisation)

Figure 3: Energy consumption for heavy duty trucks (GVWR: 40 t, Euro-VI a-c, motorway, hilly) as a function of load weight shows an example of energy consumption per vehicle-km and per tonne-km depending on load weight, including values for the three freight types.

Figure 3: Energy consumption for heavy duty trucks (GVWR: 40 t, Euro-VI a-c, motorway, hilly) as a function of load weight



Source: Handbook Emission Factors for Road Transport 4.2 [INFRAS, 2023]

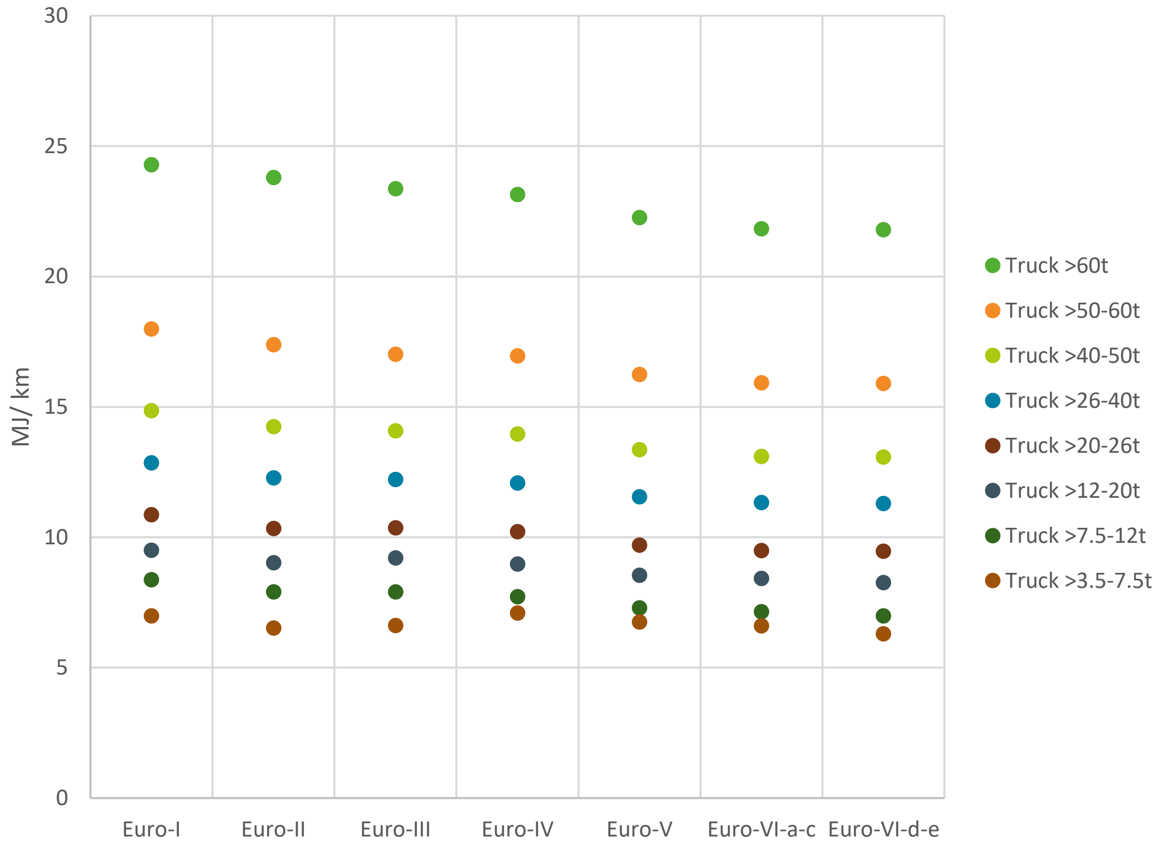
Notice: Load for volume/average/bulk goods including empty trips

EcoTransIT World considers three typical driving patterns: one for highway traffic, one for traffic on extra urban roads and one for traffic on urban roads, The mix of traffic situations is based on the German conditions[9].

Since energy demand varies depending on truck size, respective Euro standard, driving patterns and vehicle load, EcoTransIT World contains over 5000 discrete energy consumption values.

Figure 4 shows an overview of the energy consumption of diesel trucks in Europe at 50% load on motorways per vehicle-kilometre.

Figure 4: Average energy consumption of European diesel trucks with 50% load on motorways for different emission standards and truck sizes



Since rigid trucks and articulated trucks in the same size class can have different empty weights depending on the body type (e. g. curtain sider vs. cargo box), EcoTransIT World allows users to enter the empty weight manually. Emission factors for slightly different truck masses are derived from the original HBEFA 4.2 data, using a linear interpolation.

9 ETW still uses the old driving patterns for Germany from HBEFA 4.2, because the recently published driving patterns have proven to be less representative for the real fuel demand.

The energy demand of trucks also depends on the road gradient. The gradient considers country-specific factors, which represent the average topology of the country ("flat", "hilly", and "mountains"). An analysis based on data from HBEFA 4.2 for Germany showed that the energy demand for trucks is between 5-12% lower when the gradient is set to 0 compared to using the average traffic situations. However, the share of gradients for the different countries in international road transports can only be estimated. No adjustments are made for "hilly countries" (Germany and most European countries). Energy consumption and emissions are assumed 5% lower for "flat countries" (Denmark, Netherlands and Sweden) and 5% higher for "mountainous countries" (Switzerland and Austria). For regions outside Europe, "hilly" values are used.

In addition to diesel powered trucks, EcoTransIT World also includes **dedicated gas trucks** using CNG (compressed natural gas) or LNG (liquefied natural gas). CNG and LNG trucks have higher specific energy consumptions than diesel, mainly due to the lower energy efficiency of the stoichiometric spark ignition engine used. Based on a review of literature and fleet park operator's data in [DLR et al., 2015] a 24% higher energy consumption compared to diesel trucks is assumed. Since HBEFA 4.2 follows a simplified approach for gas trucks, instead of using the HBEFA values directly, we apply the +24% energy demand as a correction factor to the values from the corresponding diesel trucks of the same size class.

The energy consumption of battery electric (BEV) trucks was derived by ifeu using a driving resistance model. The model was first calibrated (e.g. speed, deceleration etc.) on the fuel consumption of Euro VI Diesel trucks according to HBEFA 4.2. In the second step, the drive train of the calibrated model was swapped from Diesel engine to electric motor. BEVs have no tailpipe emissions and use electricity as their only fuel. They have usually a higher empty weight than their conventional counterparts due to the addition of the battery. This might lower the maximum payload. However, the energy efficiency is much higher due to the high efficiency of the motor and recuperation. The electricity consumption values used in EcoTransIT World include charging losses of 14%.

Table 44: TTW energy consumption (MJ/km) of electric trucks in Europe, including. charging losses (motorway)

Size Class	Empty 0%	Average 50%	Full 100%
Truck <7.5t	2,5	2,8	3,2
Truck 7.5-12t	2,9	3,3	3,6
Truck 12-20t	3,0	3,4	3,9
Truck 20-26t	3,2	3,8	4,3
Truck 26-40t	4,0	5,0	5,9

Source: own calculations (ifeu)

It must be mentioned that the energy consumption values used for FCEV, and to some extent also for BEV, provide only a rough picture and include uncertainties that are hard to quantify at present. As alternative trucks become more common and data becomes available, emission factors should be reviewed. Furthermore, the processes for energy generation greatly differ for the different energy types (see chapter 0). These emissions must be included for an adequate comparison of emissions, especially for electric trucks. Emissions from vehicle construction are not yet within the scope of EcoTransIT World but can contribute relevantly to lifecycle emissions (i.e. battery production (see also chapter 0)).

Energy demand of US trucks

For the determination of values for trucks in North America, the emission model MOVES5 [US EPA, 2024] was used. Total annual emissions and activity data were calculated with MOVES on national level (differentiated by model year, size class, fuel type, road type and emission process). Off-network emissions were redistributed on the other four road types according to the mileage. Before calculating emission factors by dividing total emissions by mileage, MOVES road types were aggregated to EcoTransIT World road types as shown in Table 45. As the average truck weights in MOVES are not the same as in EcoTransIT World, the energy consumption (and emission factors proportional to it, e.g. CO_2) were corrected for the weight difference. This was done using the same approach as for the load factor dependency, as explained below.

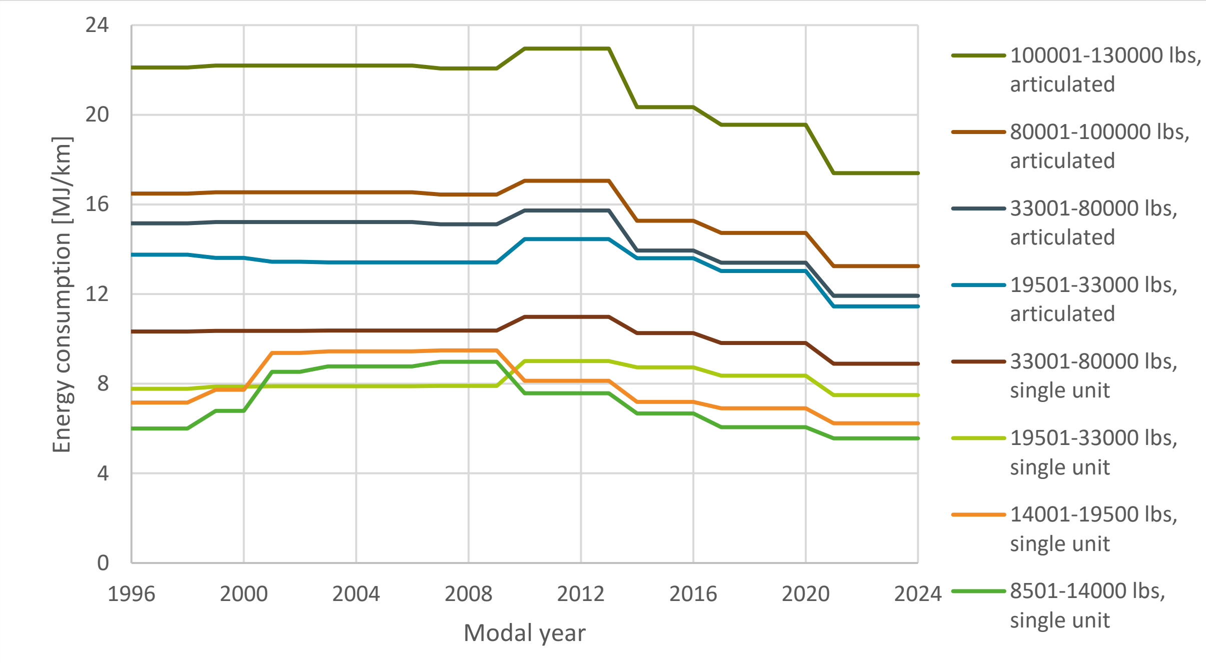
Table 45: Correspondence between MOVES and EcoTransIT World Road types

MOVES	EcoTransIT World
Rural Unrestricted Access	Rural
Urban Unrestricted Access	Urban
Rural Restricted Access	Motorway
Urban Restricted Access	Motorway

Since MOVES5 does not differentiate by the load factor, for US trucks, the load factor impact was derived from HBEFA. In this case, the impact of the load factor was only modelled for energy consumption and emissions directly proportional to it (e.g. CO_2). Hence, pollutant emissions of US trucks such as NO_x are independent from the load factor in EcoTransIT World and are always taken from the original MOVES data. The load factor dependency of energy consumption was transferred from HBEFA to MOVES using the quantity $\frac{\Delta E}{\Delta m}$ (E: energy, m: mass), i.e. the change in energy consumption divided by the change in vehicle mass.

MOVES5 includes trucks up to 80,000 lbs. Therefore, the 100,000 lbs and the 130,000 lbs trucks could not be taken directly from MOVES. Instead, their energy consumption und emissions were derived by ifeu based on HBEFA data and MOVES data for 80,000 lbs trucks. Figure 5 exemplarily shows the energy consumption as a function of the model year for North American trucks.

Figure 5: Average energy consumption of North American diesel trucks on motorways vs. model year per size class (50% load)



To calculate the energy consumption of North American battery electric trucks, EcoTransIT World follows the approach of MOVES5, but does not use the same values. In MOVES5, the energy consumption of BEV trucks is determined by dividing the energy consumption of the corresponding diesel truck by the so-called energy efficiency ratio (EER). For the following reasons, EcoTransIT World does not use the EERs from MOVES5: Firstly, MOVES5 only gives a mixed EER for both BEV and FCEV trucks. Secondly, the values are calculated by taking a simple average over several sources that differ greatly from each other. Lastly, MOVES' EERs are not differentiated by truck size, road type or load factor. This is why EcoTransIT World uses EERs derived from European diesel and BEV trucks. They are then applied to the energy consumption of diesel trucks from MOVES5 to calculate the electricity consumption of North American BEV trucks. This enables EcoTransIT World to use EERs that are differentiated by truck size, road type and load factor. Furthermore, as for European BEV trucks, the energy consumption values for North American BEV trucks include charging losses.

For North American fuel cell electric vehicles (FCEV, i.e. hydrogen trucks), a similar approach was used. Based on European data on BEV and FCEV, energy efficiency ratios between these two engine types were calculated and then applied to the energy consumption of North American BEV trucks to obtain the hydrogen consumption of North American FCEV trucks.

Additional energy demand for cooled trucks

Most refrigerated transports on articulated trucks rely on using an intermodal shipping container (reefer) with an active cooling unit. Energy demand as well as air pollutant operational emissions of reefers are described in chapter 3.6.1. To assign the reefer emissions to the transport of cooled goods on trucks, the average speed of 45 km/h for trucks (including breaks) is used based on [Weidema et al., 2013].

There are also smaller refrigerated trucks in operation with an insulated box compartment and an integrated cooling unit. Their cooling machine is most often usually powered by the main truck engine (assumed for EcoTransIT World) but may also be powered by a separate diesel engine.

For rigid trucks (≤40t) using a cooled box we assume that the truck's cooling unit is powered by the main diesel engine. This results in an additional diesel consumption [Tassou, S.A. et al., 2009] between 15 and 25% according to [Tassou, S.A. et al., 2009]. To give a rough estimate of the additional fuel consumption for a cooled box, 20% is added to the fuel consumption. The energy consumption also depends on how often the cooling compartment is opened, which is especially relevant for distribution trucks. Due to low data availability no distinction between multi-drop or single drop is done. The same approach for cooled transports is used for all trucks worldwide. In EcoTransIT World, the following options are available for cooled road transport (see Table 46).

Table 46: Available options for cooled road transport

Region	Size/ Fuel type	Cooled box	Reefer container
Europe	LCV N1-III Diesel	X	
	LCV N1-III Gasoline	X	
	Truck >3.5-7.5 t (rigid) Diesel	X	
	Truck >7.5-12 t (rigid) Diesel	X	
	Truck >12-20 t (rigid) Diesel	X	
	Truck >20-26 t (rigid) Diesel	X	
	Truck >26-40 t (tractor-trailer) Diesel	X	X (as 44t truck)
	Truck >40-50 t (tractor-trailer) Diesel		X
	Truck >50-60 t (tractor-trailer) Diesel		X
	Truck >60 t (tractor-trailer) Diesel		X
North America	Truck >8,500-14,000 lbs (single unit) Diesel	X	
	Truck >14,000-19,500 lbs (single unit) Diesel	X	
	Truck >19,500-33,000 lbs (single unit) Diesel	X	
	Truck >19,500-33,000 lbs (articulated) (Diesel)	X	
	Truck >33,000-80,000 lbs (single unit) (Diesel)	X	
	Truck >33,000-80,000 lbs (articulated) (Diesel)	X	
	Truck >33,000-80,000 lbs (articulated, glider) (Diesel)	X	X
	Truck >80,000-100,000 lbs (articulated) (Diesel)		X

	Truck >8,500-14,000 lbs (single unit) (Gasoline)	X	
	Truck >14,000-19,500 lbs (single unit) (Gasoline)	X	
	Truck >19,500-33,000 lbs (single unit) (Gasoline)	X	
	Truck >33,000-80,000 lbs (single unit) (Gasoline)	X	
	Truck >33,000-80,000 lbs (articulated) (Gasoline)	X	

5.3.2 Refrigerant losses (road)

Refrigerant losses occur both for trucks with a cooled box as well as for reefer containers transported on articulated trucks. A description of how the refrigerant losses were derived is found in chapter 3.6.2.

5.3.3 Methane emissions (road)

Both HBEFA 4.2 and MOVES5 do not only include the energy demand, but also the operational emissions of other substances such as methane. EcoTransIT World thus uses the values for methane emissions from both sources directly (currently except for gas trucks in Europe, which are derived from the diesel trucks). Generally, the impact of methane operational emissions for diesel trucks is very small.

For North American gas trucks (derived from MOVES5), methane emissions of CNG trucks lead to a considerable increase of their GHG emissions. Methane emissions may increase the operational GHG emissions of CNG trucks by 3 to 25% depending on the respective model year.

For European CNG trucks, the impact of methane emissions to the overall operational GHG emissions is below 1% in the HBEFA 4.2. Since literature sources state that methane slip for SI engine gas trucks is a relevant factor, methane slip is probably underestimated, and these factors should be checked and updated.

5.4 Air pollutant operational emissions (road)

Operational emissions of the air pollutants NO_x, NMHC and PM are directly taken from HBEFA 4.2 for trucks in Europe and from MOVES5 for trucks in North America. They are provided with the same granularity as the energy demand (except load factor dependence for North American trucks) and the operational methane and nitrous oxide emissions.

Table 47 shows an excerpt from the operational emissions of air pollutants used in EcoTransIT World for European trucks.

Table 47: NO_x, NMHC and PM emissions (TTW) of selected diesel trucks with different load factors in Europe (motorway, average gradient for hilly countries)

Emissions	Vehicle Type		Empty 0%	Average 50%	Full 100%
NO_x-Emissions (g/km)	Truck >26-40t	Euro-I	7.7	10.0	12.3
		Euro-II	7.9	10.2	12.6
		Euro-III	5.9	7.7	9.7
		Euro-IV	3.7	3.8	4.6
		Euro-V	2.9	3.1	3.4
		Euro-VI a-c	0.6	0.4	0.5
		Euro-VI d-e	0.5	0.3	0.3
NMHC-Emissions (g/km)	Truck >26-40t	Euro-I	0.483	0.469	0.497
		Euro-II	0.318	0.311	0.333
		Euro-III	0.304	0.284	0.305
		Euro-IV	0.026	0.031	0.036
		Euro-V	0.036	0.039	0.044
		Euro-VI a-c	0.015	0.018	0.023
		Euro-VI d-e	0.025	0.026	0.028
PM-Emissions (g/km)	Truck >26-40t	Euro-I	0.269	0.318	0.377
		Euro-II	0.129	0.156	0.192
		Euro-III	0.148	0.146	0.172
		Euro-IV	0.038	0.043	0.047
		Euro-V	0.038	0.043	0.046
		Euro-VI a-c	0.010	0.009	0.009
		Euro-VI d-e	0.002	0.003	0.004

Source: Handbook Emission Factors for Road Transport 4.2 [INFRAS, 2023]

It shows that air pollutant emissions decrease considerably for higher emission standards.

Since less information is available on real world air pollutant emissions (NO_x, NMHC and PM) of gas trucks, it is assumed for European gas trucks that their operational air pollutant emissions are similar to diesel trucks. However, Euro V CNG and LNG trucks have lower PM emissions, which are like Euro VI diesel trucks. This is because spark ignited gas engines have very low PM emissions, even without using particle filters [TNO, 2017]. The SO_x emissions depend on the sulphur content, which is assumed to be 3.5 ppm and therefore lower than for diesel [TNO, 2011].

For Japanese trucks, the operational air pollutant emissions of European trucks are adapted using a correction factor (see Table 48) based on a comparison between the limit values of the EU and the Japanese emission standards.

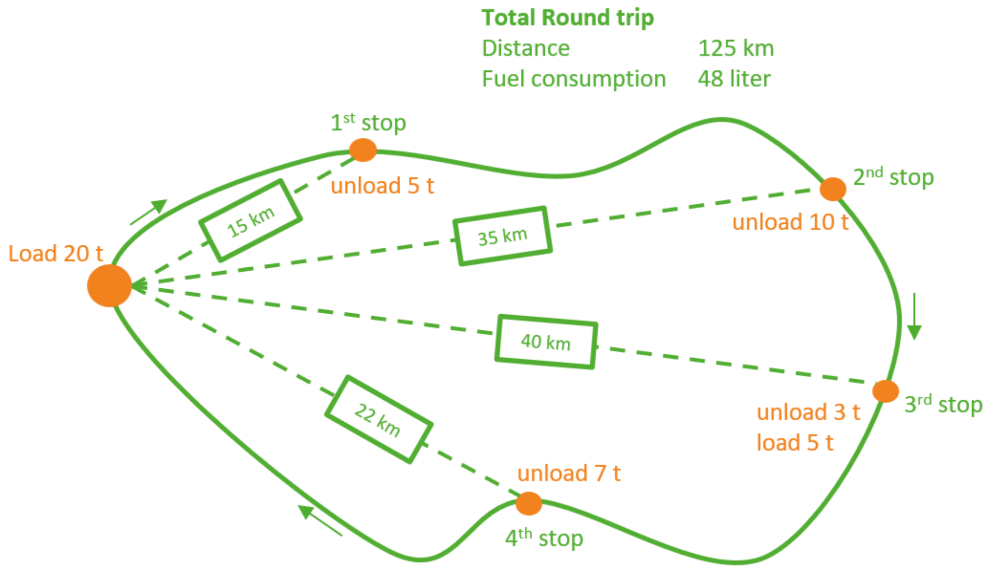
Table 48: Correction factors for operational air pollutant emissions for Japanese trucks

EU	Japan	Correction factor NO_x	Correction factor PM
Euro-I (1992)	JP 1994	1	1
Euro-II (1996)	JP 1997	1	1
Euro-III (2000)	JP 2003	1	1
Euro-IV (2005)	JP 2005	1	1
Euro-V (2008)	JP 2009	1.17	0.38
Euro-VI a-c (2013)	JP 2016	0.24	0.24
Euro-VI d-e (2019)	not available	-	-

5.5 Allocation: Collection and delivery rounds

Collection and delivery rounds (CoDi) are journeys in which goods are picked up and/or delivered at various locations along a vehicle's route. It does not make sense to allocate the GHG emissions of a pick-up and delivery tour to the freight based on the actual distances travelled, as freight that is delivered early in the tour would perform significantly better than freight that remains in the vehicle for a long time, the total emissions of the CoDi are allocated proportionately to the individual shipments.

Figure 6: Exemplary Collection & Delivery round trip



$$Percentage\ 2^{nd}\ stop = \frac{10t \cdot 35km}{5 \cdot 15 + 10 \cdot 35 + (3+5) \cdot 40 + 7 \cdot 22} = 38.9\ \%$$

Source: EcoTransIT World, IVE

EcoTransIT World uses the great-circle distance (GCD) between the CoDi start location and the respective pick-up or delivery location of a shipment for the calculation. The transport activity is determined for each shipment as part of the CoDi calculation. The share of the individual shipment transport activity is then calculated with the sum of all transport activities. The resulting percentage corresponds to the share of total CoDi emissions.

This principle can be applied to closed or open CoDi tours. In the case of a closed tour, the CoDi starts and ends at the same location. In this case, EcoTransIT World automatically adds a final leg back to the start location if required. In the case of an open CoDi, the end location may differ from the start location. The calculation of CoDi tours should be combined with a truck load analysis (FTL or FCL) to model the individual route sections in detail. The calculation of CoDi tours is currently only available in the Soap (XML) and REST (JSON) API.

6 Air transport

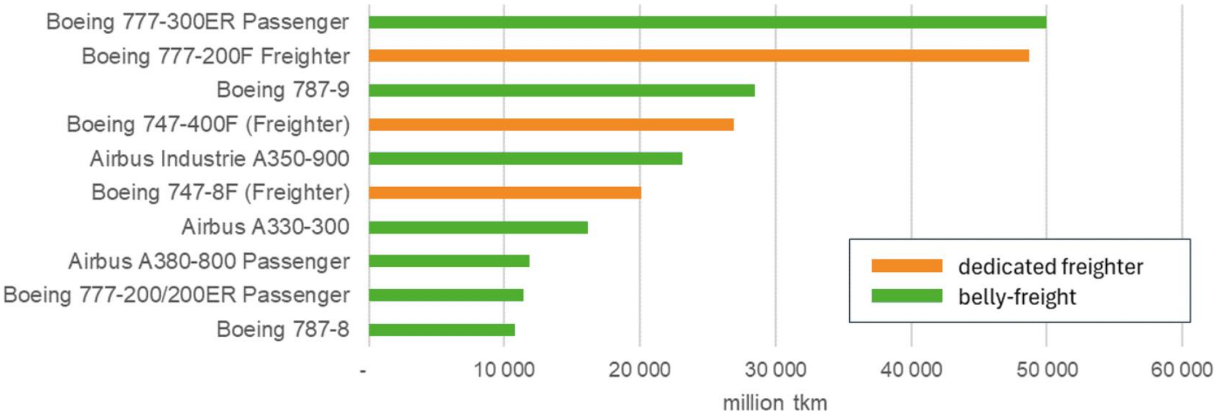
6.1 Air freight Transport Operation Categories (TOCs)

The transport operations categories (TOC) for air transport in EcoTransIT World correspond to aircraft types based on IATA (international Air Transport Association) codes (e.g. “320” for an Airbus 320, or “73Y” for a Boeing 737-300SF). A list of all aircraft types corresponding to IATA codes in use during a given year is available. The applicable aircraft types for a given emission calculation are determined based on the available flight services for the selected origin and destination (see Chapter 6.2); the emissions are calculated for all applicable aircraft types and a tkm-weighted average is returned.

Each available aircraft type is characterized by following parameters:

- Aircraft type: dedicated freighter, or passenger aircraft with belly freight;
- Maximum payload [t];
- Number of seats (for passenger aircraft only);
- Fuel code for linking to the correct fuel consumption values (see Chapter 6.3.1);
- Emission code for linking to the correct emission factors (see Chapter 6.4).

Figure 7: Aircraft types with the highest cargo transport performance (in million tkm) in 2024



If no flights exist between a selected origin-destination airport pair in the data source (either Skailark or OAG, see Chapter 6.2), so called “hybrid aircraft” are used. These “hybrid aircraft” are a mixture of representative aircraft types for three distance classes, each consisting of 60% dedicated freighters and 40% passenger aircraft[10]. Table 49 lists the representative aircraft types forming the “hybrid aircraft” for each distance band.

Table 49: Characteristics of representative aircraft types forming the “hybrid aircraft” by distance band

Type	Distance band	Representative aircraft type	IATA aircraft code	Design range [km]	Max. payload [t]	Typical number of seats
Dedicated freighter	Short haul (<1000 km)	Boeing 737-300SF	73Y	3,030	19.7	
	Medium haul (1000 – 3700 km)	Boeing 767-200F	76X	5,790	45.0	
	Long haul (>3700 km)	Boeing 747-400F	74Y	8,250	113.0	
Passenger aircraft (belly freight)	Short haul (<1000 km)	Embraer 190	E90	3,330	1.4	98
	Medium Haul (1000 – 3700 km)	Airbus 320	320	5,700	2.4	150
	Long haul (>3700 km)	Boeing 747-400	744	13,450	16.8	416

Sources: [Lang, 2007, 2009; LCAG, 2014]

6.2 Air freight transport activity

6.2.1 Distance calculation and routing

Beside the network-based routing of the other transport modes in aviation EcoTransIT World calculates the Great Circle Distance (GCD) between the origin and destination airport and adds 95 kilometres for starting and landing. An additional DAF is not included by default but can be specified by parameter.

10 Before the Covid pandemic, between 40% and 53% of freight tonne-kilometres in air cargo was transported by freighter (lower value: [Statista, 2018]; higher value: [Statista, 2022]). In March 2020, the share of cargo transported in passenger planes (belly-freight) was at 4% due to the massive drop in air travel during the pandemic [Knowler, 2022]. In summer 2022, with the normalization of passenger travel especially between Europe and the Americas, the value was at 28% of the global total again [Knowler, 2022]. This value is still relatively low, especially considering that global cargo capacity is almost back to the value of 2019 [Whelan, 2022]. Various sources expect the air traffic market to have recovered to 2019 levels in 2023 or 2024.

Additional to the distance between two airports, third-party data is used to identify trips and needed stopovers (compare chapter 3.4.4). EcoTransIT World differentiates between satellite-based (source Skailark) and scheduled (source OAG- Official Airline Guide) flight data.

OAG flight data

OAG data reflects the planned aviation timetable and consists of about two to three million of flights. In addition to Skailark data (see below), it contains flight numbers for road or train feeder services. Each flight contains following information:

- Origin and departure location (IATA code)
- Flight number, including carrier code
- Plane type as IATA plane code and the respective frequency within the timetable period
- Date and time of departure and arrival (as UTC time)
- If applicable road or train feeder service information (RFS)
- Information of the flight loop per flight number (based on an OAG internal model)

Depending on the specified routing method, EcoTransIT World calculates the aircraft share based on the trips of the Skailark data (default methodology) or based on the aircraft frequencies from OAG.

Skailark flight data

The data from Skailark includes about 30 million flights per year which are provided to EcoTransIT World on a quarterly basis. The dataset reflects real flights identified by satellite-data. Each flight information consists of detailed flight information, such as:

- Origin and departure location (IATA code)
- Flight number including carrier code
- Plane type as IATA plane code
- Date and time of departure and arrival (as UTC time)
- Carrier type, like ultra-low cost, regional or integrated cargo carrier
- Additional information required for the Skailark fuel consumption calculation

Based on this data EcoTransIT World generates trips which are used to identify one or more needed stopovers, and the respective airplane share between an airport pair.

In addition, the Skailark routing variant also contains OAG data on road and train feeder services if these are not included in the satellite-based flight information.

6.2.2 Transfer location identification

If no airport is specified directly in the calculation request, EcoTransIT World applies its transfer location identification where the freight can be transhipped to the most suitable airport. The assessment considers all suitable airports near the origin and destination. Based on the available connections between the selected nearby airports EcoTransIT World determines the most appropriate solution, considering factors such as fewest stopovers, high flight frequency and minimal detour due to stopovers.

6.2.3 Air freight types, payload, and utilization

Default accounting

The payload capacity of airplanes is limited by the maximum zero fuel weight (MZFW). Hence the payload capacity is the difference between MZFW and the operating empty weight of aircraft (including kerosene). Typical payload capacities of freighters range from approximately 13 tonnes (small aircraft) up to 130 tonnes (large aircraft). Only a few very small freighters provide a capacity lower than 10 tonnes (e.g. Cessna 208b Freighter, ATR 42-300F, ATR 72-200F). Passenger airplanes have a limited payload capacity for freight, approximately between 1-2 tonnes (medium aircraft) and 23 tonnes (large aircraft such as the Boeing 777). Small passenger aircraft only have a payload capacity for belly freight on the scale of 100 kg.

Mainly high value volume or perishable goods are shipped by air freight and the maximum allowed weight is limited. Therefore, only the volume goods category is considered for airfreight in EcoTransIT World – regardless of the input mode (standard or extended). Other types of goods, such as bulk are or average are not available.

As indicated previously, air cargo is either transported as belly freight or in dedicated freighter planes. The maximum payload for the representative aircraft types used in the standard mode, categorized by distance band, is shown in Table 49. Capacity utilization depends on the freight type and the distance band and is displayed in Table 50.

Table 50: Air cargo capacity utilization by freight type and distance band

Aircraft cargo type	Short haul (<1000 km)	Medium haul (1000 – 3700 km)	Long haul (>3700 km)
Passenger aircraft	65%	70%	80%
Dedicated freighter	50%	70%	70%

Sources: [BEIS, 2016; Djibo, 2018; Lufthansa, 2014]

Skailark accounting

To elaborate on the cargo load factor estimations for cargo aircraft, the primary goal is to maximize utilization by achieving a desired load factor of 70%, although most cargo airlines typically operate within a range of 50% to 70% capacity [Raghavendra Totamane, 2014]. This is further substantiated by the IATA Air Cargo Analysis Report, which indicates an average cargo load factor of 42% across the total market [IATA, 2023a]. Completing these findings, the Skailark data set – which encompasses all global flights, including non-cargo cargo flights, such as ferry, test, and check flights- indicates, after methodological adjustments, a representative optimal load factor of 50%.

In contrast, the load factors of passenger airlines' load factors vary based on the carrier type. For example, wide-body full-service carrier airlines may exhibit a higher proportion of cargo load compared to narrowbody ultra-low-cost carrier airlines. This discrepancy arises from the lower load capacity of narrow-body aircraft, which aligns with the business strategy of low-cost carriers (LCCs) that prioritize higher passenger occupancy.

Table 51: Weight Load Factor Table based on (flight role, aircraft type, and carrier type)

Flight Role	Aircraft Type	Carrier Type	Load factor passenger flights*	Load factor cargo flights
Passenger flight	NB	Not clearly defined	Actual passenger load factors	0.2
Passenger flight	NB	Value	Actual passenger load factors	0
Passenger flight	NB	ULCC	Actual passenger load factors	0
Passenger flight	NB	Cargo	Actual passenger load factors	0.2
Passenger flight	NB	FSC	Actual passenger load factors	0.2
Passenger flight	NB	REG	Actual passenger load factors	0.2
Passenger flight	REG	Not clearly defined	Actual passenger load factors	0
Passenger flight	REG	Cargo	Actual passenger load factors	0
Passenger flight	REG	REG	Actual passenger load factors	0
Passenger flight	REG	ULCC	Actual passenger load factors	0
Passenger flight	REG	FSC	Actual passenger load factors	0
Passenger flight	REG	Value	Actual passenger load factors	0
Passenger flight	WB	Cargo	Actual passenger load factors	0.2
Passenger flight	WB	ULCC	Actual passenger load factors	0
Passenger flight	WB	REG	Actual passenger load factors	0.2
Passenger flight	WB	Value	Actual passenger load factors	0.4
Passenger flight	WB	FSC	Actual passenger load factors	0.4
Passenger flight	WB	Not clearly defined	Actual passenger load factors	0.2
Cargo flight	NB	Not clearly defined		0.5
Cargo flight	NB	Value		0.5
Cargo flight	NB	ULCC		0.5
Cargo flight	NB	Cargo		0.5
Cargo flight	NB	FSC		0.5
Cargo flight	NB	REG		0.5
Cargo flight	REG	Not clearly defined		0.5
Cargo flight	REG	Cargo		0.5
Cargo flight	REG	REG		0.5
Cargo flight	REG	ULCC		0.5
Cargo flight	REG	FSC		0.5
Cargo flight	REG	Value		0.5
Cargo flight	WB	Cargo		0.5

Cargo flight	WB	ULCC		0.5
Cargo flight	WB	REG		0.5
Cargo flight	WB	Value		0.5
Cargo flight	WB	FSC		0.5
Cargo flight	WB	Not clearly defined		0.5

Aircraft Type Definitions:

- NB (Narrow-body aircraft), e.g. 73H, 320, 32N
- WB (Wide-body aircraft), e.g. 77W, 333, 789
- REG (Regional aircraft), e.g. E7W, AT7, CR9

Carrier Type Definitions:

- ULCC (Ultra Low-Cost Carriers): offer low fares with minimal service FSC (Full-Service Carriers): provide a premium flying experience through a wide range of passenger service offerings Value Carrier: balance low fares with selected services. REG - Regional Carriers: operate on short routes with smaller aircraft, connecting regional airports to major hubs.

Cargo-only Carriers: transport goods using dedicated freight aircraft or cargo space in passenger planes. Payload estimates for passenger flights are derived from the revenue & pax model, a statistical model utilizing machine learning techniques. This model ensures that passenger load factor values reflect reality and enhances accuracy while minimizing errors.

The revenue & pax model operates as follows:

- **Origin and Destination (O&D) Creation:** Possible O&D pairs are created from flight-level data.
- **Training Data Integration:** Data from various sources, including actual passenger numbers at the city-pair level, fare information, and passenger share, are integrated.
- **Addition of Explanatory Variables:** Supply-side data for each flight, such as flight distance, combined with geographical and socio-economic variables, are introduced into the statistical framework.

This model enables the estimation of passenger numbers for flights worldwide, resulting in the calculation of passenger payload. Using the total payload provided by each aircraft manufacturer, the cargo payload is then determined by subtracting the passenger payload from the total payload.

6.3 Air freight GHG activities

6.3.1 Energy consumption (air)

Available energy consumption calculation methods

Energy consumption of air transports can be calculated by two different methods in EcoTransIT World:

- Based on the "Small Emitters Tool" (SET) [Eurocontrol, 2023]
- Based on Skailark data/method [Skailark, 2023]

Small Emitters Tool (SET)

The SET method is a simple empirical approach based on measured fuel-burn data by aircraft type that has been developed on behalf of the European Commission for reporting under the European Emissions Trading Scheme (ETS)11 [Eurocontrol, 2023]. It is based on linear regressions that are derived based on measured fuel consumption data per aircraft type; for some aircraft, one regression equation is used over the entire range of possible flight distances (see the example of a Boeing 747-400 in Figure 8), while for others, up to three distance bands are differentiated with separate equations.

The consequence of this statistical approach is that fuel consumption of a particular flight may differ from the SET estimate (e.g. due to differences in take-off weight – in turn caused by variability in passenger numbers, cargo utilization, or fuel loaded – or different weather conditions, different routes, aircraft variants etc.), but on average, the SET provides an accurate estimate of fuel consumption.

The SET is updated annually using samples of actual fuel-burn data provided by volunteer aircraft operators in Europe, based on their flights from a specific year. EcoTransIT World integrates the latest version of the SET data in each update. The SET version currently deployed in EcoTransIT World is Version 5.12.1 [Eurocontrol, 2023]).

The current SET version encompasses 1043 aircraft types. Fuel consumption is derived as follows [Astorino, 2009; Eurocontrol, 2023]:

- Measured fuel consumption is available for 113 aircraft types.
- For 44 aircraft types, the measured data of similar plane types are adjusted by using a correction factor based on the MTOW (maximum take-off weight) ratio.

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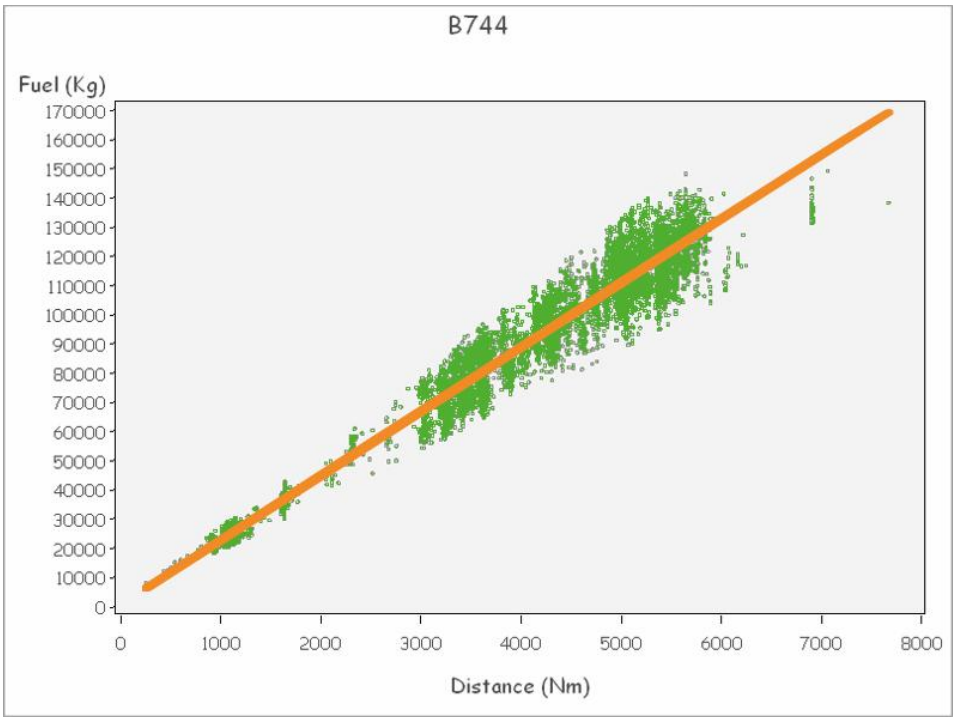
11 See https://www.eurocontrol.int/tool/small-emitters-tool

- For about 30 aircraft types, data from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (formerly called the CORINAIR Emission Inventory Guidebook) is used.
- For the remaining aircraft types, the average fuel consumption per flight kilometre is calculated based on a linear regression model based on the available data considering the MTOW of each airplane.

Figure 8: TTW energy consumption of the Small Emitters Tool is based on a linear regression of fuel-burn data collected in Europe – example of a Boeing 747-400 (Source: [Astorino, 2009]).



Since the Small Emitters Tool contains fuel-burn data for only one aircraft model (e.g. Boeing 747-400), this data is applied to both dedicated freighter and passenger aircraft (see Table 52: Boeing 747-400F). Table 52 illustrates the energy consumption of the six airplane types used to calculate the "hybrid aircraft", by discrete travel distances. These energy consumption values are directly based on measured fuel-burn data from the Small Emitters Tool. For distances between the discrete mission distances given in Table 52 (e.g. between 4,630 and 5,556 km) the fuel consumption of the aircraft is interpolated linearly. The fuel consumption values in kg from the Small Emitters Tool are converted to energy consumption using the fuel properties given in Chapter 4.

Table 52: Kerosene consumption of selected freighter and passenger aircraft by flight distance [Eurocontrol, 2023]

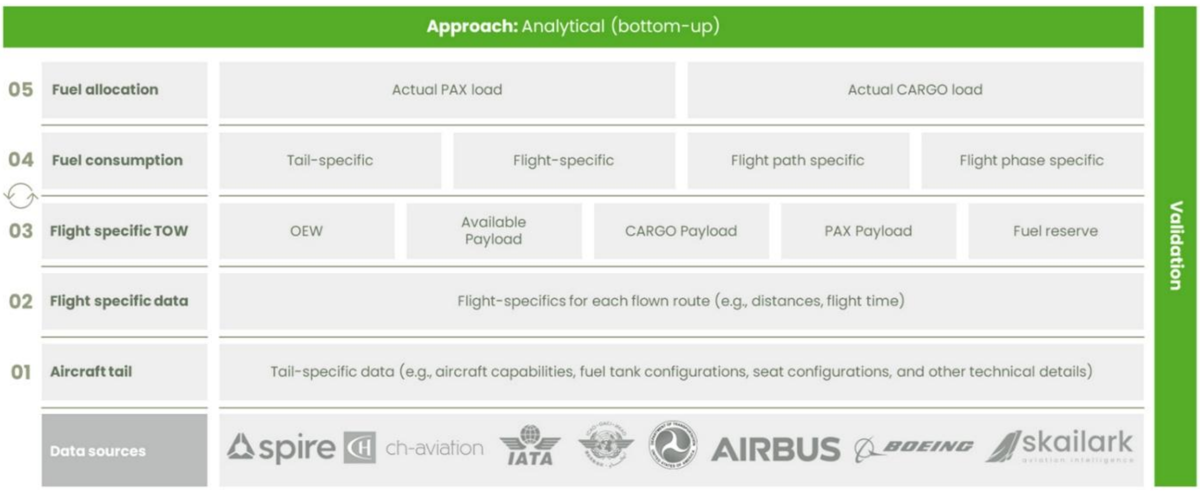
Distance [km]	Dedicated freighters			Passenger aircraft		
	Boeing 737-300SF [kg]	Boeing 767-200F [kg]	Boeing 747-400F [kg]	Embraer 190 [kg]	Airbus 320 [kg]	Boeing 747-400 [kg]
232	1'535	2'526	6'124	1'284	1'657	6'124
463	2'271	3'774	8'732	1'832	2'361	8'732
926	3'742	6'271	13'947	2'930	3'770	13'947
1'389	5'213	8'767	19'163	4'027	5'179	19'163
1'852	6'684	11'264	24'378	5'124	6'588	24'378
2'778	9'626	16'257	34'809	7'318	9'406	34'809
3'704	12'568	21'250	45'240	9'513	12'224	45'240
4'630	15'510	26'244	55'670	11'707	15'042	55'670
5'556	18'452	31'237	66'101	13'902	17'860	66'101
6'482	21'394	36'245	76'532	16'096	20'678	76'532
7'408	24'336	41'344	86'962	18'291	23'496	86'962
8'334	27'278	46'443	99'287	20'485	26'314	99'287
9'260	30'220	51'542	111'612	22'679	29'132	111'612
10'186	33'162	56'640	123'938	24'874	31'949	123'938
11'112	36'104	61'739	136'263	27'068	34'767	136'263
12'038	39'046	66'838	148'588	29'263	37'585	148'588
12'964	41'987	71'937	160'913	31'457	40'403	160'913
13'890	44'929	77'036	173'238	33'652	43'221	173'238

Source: [Eurocontrol, 2023]

Skailark accounting

Skailark offers a bottom-up approach to fuel modelling of individual passenger and cargo flights based on granular data and current research. Skailark's main customers include airlines and freight forwarders. The modelling approach follows five main steps, which are presented and described below.

Figure 9: Skailark fuel modelling approach



Aircraft data

Granular aircraft and flight supply data are the basis of Skailark's fuel calculation. The data collection process begins with gathering aircraft-specific information, such as individual aircraft capabilities, cruise mach, fuel tank configuration, maximum payload and other technical details using Skailark's proprietary aircraft model. This data is updated regularly, for example when a new aircraft entering the market. Sources used to build Skailark's aircraft data model are for instance manufacturer documentation provided by Airbus [Airbus, 2023] , Boeing [Boeing, 2021], or other aviation-related sources, such as official aircraft information provided by ICAO [ICAO, 2023].

Flight-specific data

In addition, flight and fleet data are utilized. This data is provided by Spire, who gather the information by utilizing satellite technology, providing real-time and historical information for flights worldwide [Spire, 2023]. This approach ensures access to the most reliable data, which is used as input for accurate calculations and analysis. Skailark possesses information on the total distance flown for each aircraft worldwide, the corresponding number of flight hours logged, the date and time of arrival and departure (scheduled flight times and actual flown flight hours), the 2-letter IATA carrier code [IATA, 2023c] under which carriers are operating at that given date, the 3-letter IATA airport codes [IATA, 2023b] and the latitude and longitude of departure and arrival airports, for instance. Currently, Skailark's flight data is updated quarterly. The flight data is enriched by fleet data, provided by Ch-Aviation [ch-aviation, 2023].

Aircraft data and flight-specific data are matched using aircraft weight information. That way, all technical details for each flight are available, allowing fuel to be calculated on a flight-by-flight and tail level.

Flight specifics take off weights

Given all technical aircraft details, aircraft weights and flown distances, Skailark calculates the technical specifications of each aircraft model for each flown flight, including:

- Operating empty weight (OEW) = maximum zero fuel weight – maximum payload
- Fuel reserve
- Fuel consumed non-cruise
- Fuel consumed cruise
- Take-off- and landing weights
- Possible available payload (Maximum payload adapted towards range of each individual flight.)
- Cargo payload (including available belly payload on passenger flights)
- 'Actual' passenger payload

The weight proportions of these parameters are incorporated as factors in the final fuel calculations. Payload and range restrictions of each flight are factored in.

Fuel consumption

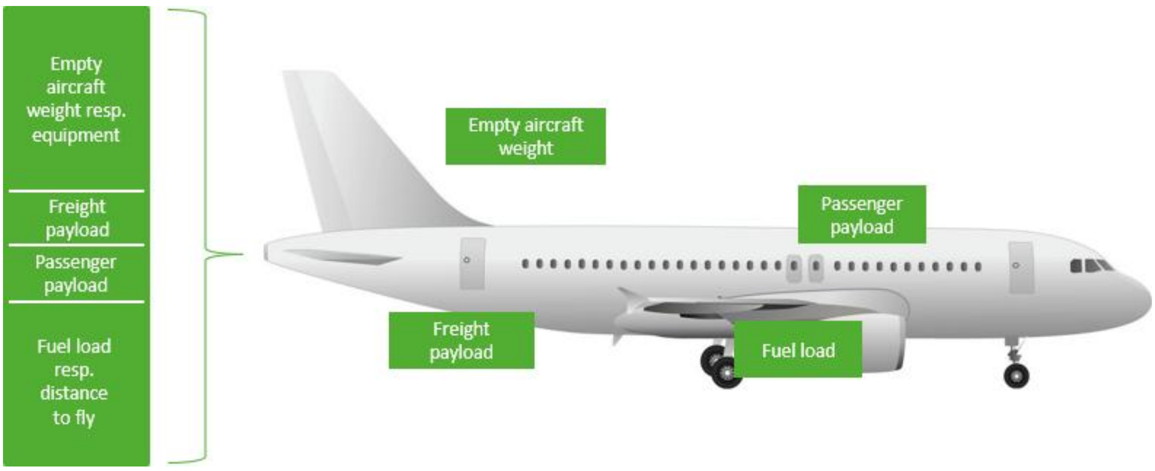
The factors considered are not limited solely to weight and duration of a flight; they also include aircraft speed, air density, and air temperature. These variables undergo changes in various flight paths and phases, contributing to a comprehensive understanding of the aviation dynamics involved in Skailark's calculations. After considering all these factors, the calculation of fuel consumption with the maximum available payload is performed based on the collection of aircraft-specific data (see Aircraft data) and flight-specific data (refer to Flight-specific data). This process enables Skailark to calculate the specific fuel requirements for both the flight and the aircraft.

Aircraft typically do not fly at their maximum theoretical range while carrying the maximum possible payload. To enhance accuracy, each aircraft's realistic load factor (LF) and payload are estimated based on its designated flight role (passenger vs. cargo flights), the aircraft type, carrier`s business model, and specific cabin setup (e.g., seat layout).

Available payload parameters are calculated for each flight sector, with calculations performed at the individual flight level. An aircraft's operational limits are constrained by its maximum take-off weight, as defined by the OEMs. To achieve maximum range, an aircraft must reduce both fuel and payload.

The applied payload load factors are shown in Table 51: Subsequently, the assumptions of the weighed LF are incorporated as a contributing factor and the fuel consumption is adapted accordingly to the allocated payload. The total payload is the sum of the passenger payload and, if applicable, the cargo payload (cargo only or belly freight).

Figure 10: Total fuel consumption dependencies (Skailark methodology)



Source: EcoTransIT World, IVE mbH

6.3.2 Methane emissions (air)

Methane emissions from air transport are currently not reported separately in EcoTransIT World, since the source used for pollutant emission factors (the aviation chapter of the EMEP/EEA Air Pollutant Emission Inventory Guidebook [EEA 2019]) does not include methane as a pollutant (see Chapter 6.4). However, they are included in the operational CO_2e emission factors for jet kerosene (Chapter 3.7). Generally, the influence of non-CO_2 GHG in aviation is low; apart from a small unburnt portion in the exhaust gas, methane slip does not occur [Santoni et al., 2011].

6.3.3 Refrigerants (air)

EcoTransIT World does currently not support calculations for cooled air freight transport, as the estimated impact of additional energy use (e.g., electricity for cooling) or potential refrigerant leakage (typically dry ice, i.e., carbon dioxide) is considered negligible compared to the overall GHG emissions of air transport.

6.4 Operational emissions (air)

CO_2, CO_2e and SO_x depend directly on the amount of kerosene consumed by the airplanes. To calculate CO_2e emissions, EcoTransIT World applies the emission factors provided by ISO 14083 without modifications (see chapter 0). To calculate For SO_x, EcoTransIT World applies an emission factor of 0.84 g per kg kerosene [EEA, 2019]. The SO_x factor is based on data from Eurocontrol. On national level, some countries use much lower values. Germany for example an emission factor of 0.4 g SO_2 per kg kerosene in 1998 and 0.2 g SO_2 per kg kerosene in 2009 is used [ifeu and Öko-Institut, 2012; Öko-Institut, 2009].

NO_x, NMHC and PM are air pollutants that are not directly related to the fuel consumption of the aircraft. For these air pollutants, EcoTransIT World uses emission factors from the EMEP/EEA Air Pollutant Emission Inventory Guidebook [EEA, 2019]. This guidebook provides detailed emission factors for NO_x, HC, and PM of around 75 different aircraft types for discrete mission distances. The data of the EMEP/EEA Guidebook is applied in different national inventories (e.g. see [ifeu and Öko-Institut, 2012] for Germany) as well as for several emission calculation tools (e.g. see [ICAO, 2012]). In this context, it must be considered that the EMEP/EEA data is based on an average fleet. The calculated values may be 10% below or above the real emissions of individual aircraft calculated for a concrete city pair [ICAO, 2012]. Nevertheless, the EMEP/EEA data is the most comprehensive publicly available data source for NO_x, HC and PM emissions of aircraft.

EcoTransIT World uses the emission data of the EMEP/EEA Guidebook [EEA, 2019] without modifications. Table 53 shows the results for the aircraft type Boeing 747-400 according to the flight distance. Since the emission values are given only for discrete mission distances, emissions for flight distances between those listed in the Table 53 are calculated by linear interpolation. In some cases, the EMEP/EEA Guidebook data doesn't cover the maximum ranges of the airplanes. For these cases, the emission values were extrapolated to cover the full range required for EcoTransIT World calculations. These extrapolation steps were done by using a polynomial regression. As the EMEP/EEA Guidebook only contains distance related emission factors for total hydrocarbons (HC), NMHC emissions have been calculated based on HC. It is assumed that the NMHC emissions for the Landing and Take-Off cycle (so-called LTO cycle, <1,000 m altitude) account for 90% of total HC emissions, while during cruise only NMHC is emitted [EEA, 2019]. The NMHC values in Table 53 include this adjustment.

Since certain air pollutants (nitrogen oxides, ozone, water, soot, sulphur) emitted at cruising altitude can amplify climate impact beyond CO_2, EcoTransIT World optionally applies an emission weighting factor (EWF)ld – please see Chapter 6.6.1 for details.

Table 53: NO_x, NMHC and PM emissions of aircraft type Boeing 747-400 (freighter). [EEA, 2019]

Distance [km]	NO_x [kg]	NMHC [kg]	PM [kg]
232	105	2.70	0.49
463	149	3.18	0.76
926	207	3.78	1.24
1,389	268	4.34	1.79
1,852	329	4.81	2.30
2,778	447	5.99	3.53
3,704	573	7.03	4.65
4,630	692	8.05	5.75
5,556	822	9.07	6.86
6,482	941	10.09	7.96
7,408	1078	11.00	8.95
8,334	1197	12.02	10.05
9,260	1343	12.84	10.95
1,186	1462	13.86	12.05
1,112	1617	14.65	12.92
12,038	1767	15.48	13.84
12,964	1886	16.51	14.94
13,890	1992	17.77	16.21

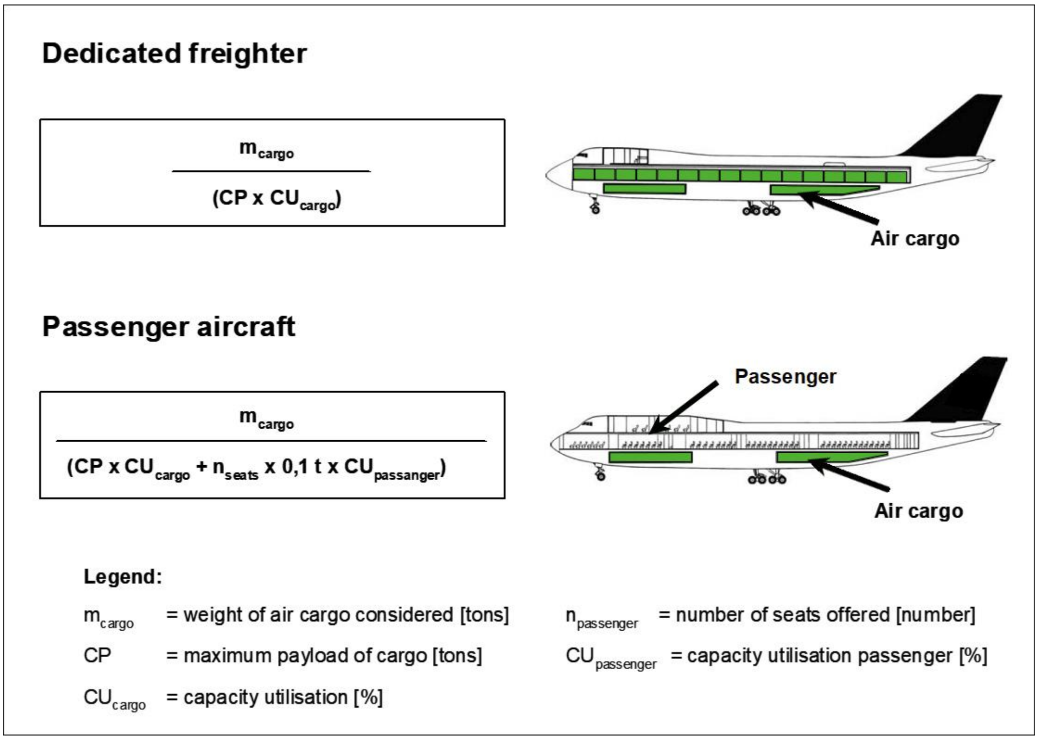
Sources: [EEA, 2019], INFRAS calculations.

6.5 Allocation: belly freight versus dedicated cargo (air)

The energy consumption and emissions of dedicated freighters can easily be allocated per leg (airport pair) using the ration of cargo weight to the total aircraft payload. The latter is the product of maximum payload capacity (CP) and the capacity utilisation (CU).

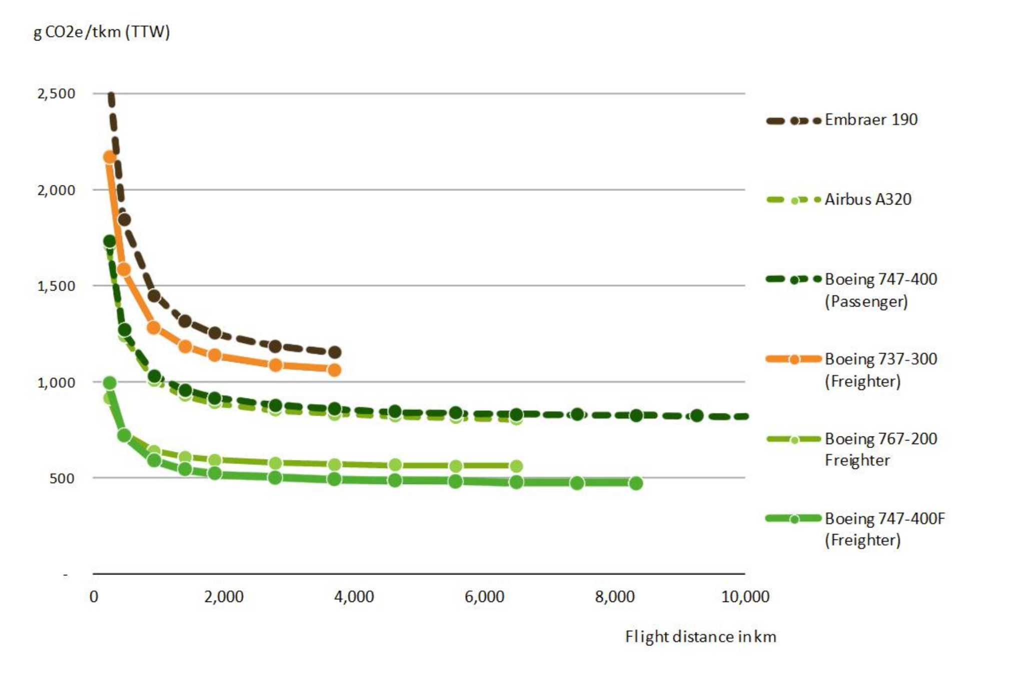
For belly freight in passenger planes, the energy consumption must be split between cargo and passengers. To allocate emissions between passenger and freight, EcoTransIT World uses the approach according to ISO 14083. ISO 14083 assumes a passenger weight of 100 kg (= 0.1 t). Figure 11 contains the concrete formula to allocate the energy consumption and emissions of passenger aircraft.

Figure 11: Allocation rules for dedicated freighter and passenger aircraft in accordance with ISO 14083.



The approach for belly freight required by ISO 14083 results in higher fuel consumption, thus emissions, for air cargo carried by passenger aircraft compared to freighters. As shown in Figure 12, CO_2 emissions from belly cargo are 20 to 80% higher than those from air cargo transported by dedicated freighters. Moreover, the figure shows that CO_2 emissions of smaller aircraft (e.g. B737-300SF) are much higher than those of larger aircraft that are used for long-haul flights (e.g. B 747-400F). In this context, it should be noted that small aircraft are used only for short-haul flights up to 1’000 km, medium sized aircraft for medium-haul flights between 1’000 and 3’700 km, and large aircraft for long-haul flights over 3’700 km within EcoTransIT World.

Figure 12: Specific aircraft operation (or TTW) CO_2 emissions of selected freighter and passenger aircraft in g/tkm.



Sources: [Eurocontrol, 2023], INFRAS calculations.

6.6 Specialties

6.6.1 Emission Weighting Factor (EWF)

Some air pollutants - particularly nitrogen oxides, ozone, water, soot, sulphur- emitted at cruising altitude can amplify climate impact beyond CO_2 [IPCC, 1999; Lee et al., 2020]. To account for these effects, the metric “Radiative Forcing Index” (RFI) or the “effective radiative Forcing” (ERF) is used. For cruise in critical altitudes over 9 kilometres, the RFI and the ERF factors lie around 2, indicating that the total climate impact of the aircraft emissions is twice the impact of TTW CO_2 emissions [Lee et al., 2020].

The disadvantage of the RFI is that it reflects only the current radiative forcing of air pollutants and water vapour, making it unsuitable to calculate CO_2e emissions, which is based on the global warming potential (GWP) of emissions measured over a period of 100 years. For this reason, the so-called Emission Weighting Factor (EWF) was developed especially for air traffic. Similar to the GWP, the EWF considers all additional climate effects of aircraft emissions compared to CO_2 over a period of 100 years [Graßl and Brockhagen, 2007].

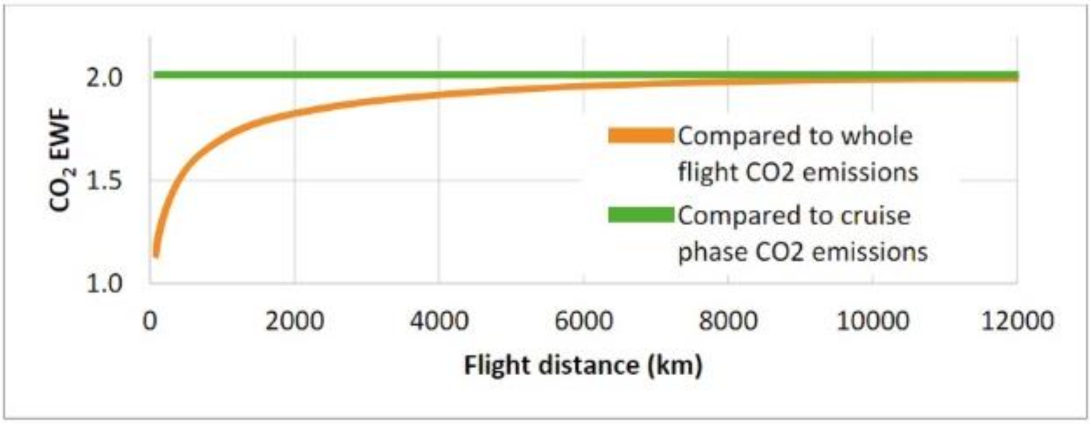
The EWF is also applied for cruising in an altitude over 9 kilometres and lies between 1.3 and 3.6 [Cox and Althaus, 2019]. EcoTransIT World user can choose to apply the EWF for theirCO_2e emissions calculation. If applied, an average EWF of 2.0 is used based on [Cox and Althaus, 2019]. Figure 13 illustrates the average EWF for the entire flight including take-off and landing in relation to the total flight distance. The EWF value is approximated using a logarithmic fit function, with a cap value of 2.0:

$$\boldsymbol{EWF} = \mathbf{min}(\mathbf{2.0},\ \mathbf{0.1612} * \mathbf{ln}(\boldsymbol{distance}) + \mathbf{0.5534})$$

This function was derived for EcoTransIT World based on [Cox and Althaus, 2019], considering the decreasing influence of the take-off and landing phases -during which no EWF applies due to lower flight altitude- on total flight emissions.

In this context it must be pointed out that ISO 14083 does not consider EWF (or RFI) for the calculation of CO_2e emissions of air transport. Since the EWF changes the results of the climate impact of air transport significantly, we propose to consider the EWF separately. This is why the application of the EWF is optional and must be explicitly selected in EcoTransIT World.

Figure 13: Approximation of EWF of total CO_2 emissions and cruise phase emissions only as a function of distance. [Cox and Althaus, 2019]



Source: [Cox and Althaus, 2019]

7 Ocean transport

7.1 Ocean freight Transport Operation Categories (TOCs)

EcoTransIT World classifies ocean transports into transport operation categories (TOCs) by aggregating vessel types. There are different options to create a TOC for ocean shipments:

Default: By trade lane and vessel/cargo type; trade lanes are representative routes covering a typical selection of vessels. Depending on the origin and destination region (Figure 14) a respective aggregated vessel type is selected in EcoTransIT World (Table 54). These trade lane-based vessel aggregations are a mix of different size-based vessel classes.

Optional: By size-based vessel classes; a size-based vessel class is reflecting representative vessels of the respective maximum Twenty-foot Equivalent Unit (TEU) capacity or maximum Deadweight Tonnage (DWT). If a size-based vessel class is not defined, EcoTransIT World automatically selects a vessel class based on the emissions area pair.

For containerized transport, only the first option applies, as the CO_2e emissions annually published by Clean Cargo are aggregated by trade lane [SFC, 2024]. For other cargo types, such as bulk or RoRo), emissions are determined using a more detailed bottom-up approach based on [IMO, 2020]. The applicable vessel types for a given emission calculation are determined based on the available vessel services between the selected origin and destination (see Chapter 7.2.1). Emissions are then calculated for all applicable vessel types, and a weighted average is returned – using tkm or TEU-km metric.

Table 54: Default Ocean TOC by vessel/cargo type and trade lane.

Vessel types	Trade lane	Aggregated size class / payload capacity
BC (liquid, dry, and General Cargo)	Suez trade	Aframax/ Suezmax
BC (liquid, dry, and General Cargo)	Transatlantic trade	Handymax / Panamax
BC (liquid, dry, and General Cargo)	Transpacific trade	Handymax/ Panamax/ Aframax/ Suezmax
BC (liquid, dry, and General Cargo)	Panama trade	Handymax / Panamax
BC (liquid, dry, and General Cargo)	Other global trade	Handysize / Handymax / Panamax / Aframax
BC (liquid, dry, and General Cargo)	Intra-continental trade	Feeder / Handysize / Handymax
CC	Suez trade	4,700 – 25,000 TEU
CC	Transatlantic trade	2,000 – 14,500 TEU
CC	Transpacific trade	1,000 – 25,000 TEU
CC	Panama trade	2,000 – 14,500 TEU

CC	Other global trade	1,000 – 25,500 TEU
CC	Intracontinental trade non-EU	500 – 3,500 TEU
CC	Intra-continental trade EU	500 – 2,000 TEU
Great Lake BC		< 30,000 DWT

Note: BC = bulk carrier, GC = general cargo vessel, CC = container vessel Source: Assumptions EcoTransIT World

Source: Assumptions EcoTransIT World

Figure 14: Global emission areas as basis for the trade lane identification

Source: IVE, EcoTransIT World

Example: For an ocean transport from a port in North Europe to the North Amerika West Coast (emission area EU to UW) the EcoTransIT World default vessel type EcoTransIT is “Panama trade” with the respective vessel class “cc-pa-a-47” for container vessels.

Table 55: Aggregated trade lane-based vessel categories per emission area pair (exemplary)

Emission area pair	Trade lane	Container	Bulk carrier	Liquid	RoRo
AS-AF	Other	cc-og-a-47	bc-og-a-120	bc-sm-l-200	roro-gt-5k
AS-MD	Suez	cc-sz-a-70	bc-sz-200	bc-sm-l-200	roro-gt-5k
AS-MI	Intra-Continental	cc-ic-a-35	bc-ic-a-35	bc-hs-l-35	roro-gt-5k
AS-UE	Other	cc-og-a-47	bc-og-a-120	bc-sm-l-200	roro-gt-5k
AS-UW	Transpacific	cc-tp-a-70	bc-tp-a-200	bc-pm-l-80	roro-gt-5k
AS-EU	Suez	cc-sz-a-70	bc-sz-200	bc-sm-l-200	roro-gt-5k
AS-OZ	Other	cc-og-a-47	bc-og-a-120	bc-sm-l-200	roro-gt-5k
AS-LA	Other	cc-og-a-47	bc-og-a-120	bc-sm-l-200	roro-gt-5k
EU-AF	Other	cc-og-a-47	bc-og-a-120	bc-sm-l-200	roro-gt-5k
EU-LA	Transatlantic	cc-ta-a-47	bc-ta-a-80	bc-sm-l-200	roro-gt-5k
EU-MI	Suez	cc-sz-a-70	bc-sz-200	bc-sm-l-200	roro-gt-5k
EU-OZ	Other	cc-og-a-47	bc-og-a-120	bc-sm-l-200	roro-gt-5k
EU-EU	Intra-Continental EU	cc-ic-eu-a-20	bc-ic-a-35	bc-hs-l-35	roro-gt-5k
MD-UE	Transatlantic	cc-ta-a-47	bc-ta-a-80	bc-sm-l-200	roro-gt-5k

Table 56: Aggregated size-based vessel categories per emission area pair (exemplary)

Emission area pair	Container	Bulk carrier	General Cargo	RoRo	Vehicle
AS-AF	cc-5000-8000	bc-60000-100000	gc-10000-20000	rr-10000-15000	rv-30000-50000
AS-MD	cc-14500-20000	bc-200000	gc-20000	rr-15000	rv-50000
AS-MI	cc-3000-5000	bc-10000-35000	gc-5000-10000	rr-0-5000	rv-0-30000
AS-UE	cc-5000-8000	bc-60000-100000	gc-10000-20000	rr-10000-15000	rv-30000-50000
AS-UW	cc-8000-12000	bc-200000	gc-20000	rr-15000	rv-50000
AS-EU	cc-14500-20000	bc-200000	gc-20000	rr-15000	rv-50000
AS-OZ	cc-5000-8000	bc-60000-100000	gc-10000-20000	rr-10000-15000	rv-30000-50000
AS-LA	cc-5000-8000	bc-60000-100000	gc-10000-20000	rr-10000-15000	rv-30000-50000
EU-AF	cc-5000-8000	bc-60000-100000	gc-10000-20000	rr-10000-15000	rv-30000-50000
EU-LA	cc-12000-14500	bc-200000	gc-20000	rr-15000	rv-50000
EU-MI	cc-14500-20000	bc-200000	gc-20000	rr-15000	rv-50000
EU-OZ	cc-5000-8000	bc-60000-100000	gc-10000-20000	rr-10000-15000	rv-30000-50000
EU-EU	cc-2000-3000	bc-10000-35000	gc-5000-10000	rr-0-5000	rv-0-30000
MD-UE	cc-12000-14500	bc-200000	gc-20000	rr-15000	rv-50000

7.2 Ocean freight transport activity

7.2.1 Distance calculation and routing (ocean)

The determination of a shipping route is based on the EcoTransIT World internal routing method (see chapter 3.4.1). The maritime network is created supported by AIS-based data and reflects the official sea routes and passages around the world. As a result, shipping routes can be divided into emission control area (ECA) and non-ECA parts.

Figure 15: Sea network around Denmark

Source: IVE, EcoTransIT World

The sea network also includes canal routes, with the maximum possible vessel sizes (TEU- or DWT-based) as an attribute. This can cause detours in routing as soon as the current vessel size exceeds the maximum canal capacity. In EcoTransIT World especially the Suez, Panama and Kiel canals are limited in terms of capacity.

Table 57: Maximum TEU and DWT canal capacities in EcoTransIT World

Canal	Maximum TEU	Maximum DWT
Suez	30.000	200.000
Panama	14.500	120.000
Kiel canal	8.000	60.000

Natural waterways, such as the St. Lawrence River from Montreal to the Great Lakes in North America or major rivers in China, are not restricted to avoid routing errors. An additional DAF is not included in the routing by default but can be specified as parameter.

AIS-based ocean shipment data by AXSMarine (former Alphaliner)

The data from AXSMarine includes about 3 million ocean trips per year which are be provided on a quarterly basis to EcoTransIT World. The dataset reflects actual vessel movements identified by AIS-data. Each vessel trip information consists detailed trip information, like

- Origin and destination location (UN/LOCODE)
- Vessel type via IMO number/vessel name
- Carrier code (SCAC)
- Container liner service as ID
- Date/time of departure and arrival (as UTC time)
- Port-calls between origin and destination locations

Based on this data EcoTransIT World generates trips which are used to identify the respective vessel share between the port pair. Depending on the selected primary data aggregation (refer chapter 3.4.4) EcoTransIT World creates a list with all sailed vessels (trips) within the selected time frame.

Realistic route filter

All vessels are operating in loops, each consisting of a sequence of ports. From this chain EcoTransIT World identifies individual trips between two ports, including any intermediate port calls. This also includes trips unlike to be used for freight transport – for example, a loop starting in Europe circling around Afrika, passing through the Panama Canal and then up to New York. Such a detour is significantly longer than a direct Europe-East Coast route. However, the realistic route filter compares all possible trips and removes those that deviate from typical shipping patterns.

The following issues may lead to a trip being excluded from the list between two ports:

- The trip has a very high detour compared to the shortest distance trips
- The lead time is significantly higher than the shortest lead time

Since filter determination is quite complex, EcoTransIT World provides a robust automatic filter, which is enabled by default. The filter can be adjusted or removed using respective parameter settings.

- Vessel (IMO number or vessel ID, vessel name)
- Container Liner service (service ID)
- Carrier (carrier ID, carrier name, standard carrier SCAC code)
- Alliance (alliance ID, alliance name)

If one or multiple of these parameters are set, only correlating vessel trips are considered in the calculation. It is also possible to aggregate a parameter to a higher category, for example to by defining an IMO number and aggregating it to the corresponding container liner service. In this case, all vessel trips of the service will be considered in the calculation.

Table 58: Aggregation combinations for Ocean shipments based on AXSMarine data

Aggregate to	Vessel	Carrier	Service	Alliance
Vessel	Use only trips of the resp. vessel	Use all trips of all vessels of the carrier of the resp. vessel (vessels where carrier is vessels operator (only if vessels operator is known)	Use all trips of the service of the resp. vessel (only applicable if the vessel sails in a service) (default)	Use all trips of all services which are in the same alliance (only applicable if the vessel sails in a service which is in an alliance)
Carrier	Use all trips of the respective carrier (only vessels where carrier is vessel operator)	Use all trips of the resp. carrier (vessels where carrier is vessel operator and all services from carrier) (default)	Use all trips of all services of the carrier (excl. all vessels which are not sailing within a service)	Use all trips of all services which are in the same alliance (only applicable if the carrier is part of an alliance)
Service	Use only trips of the resp. service (default)	Use all trips of all services of all carriers of the resp. service	Use only trips of the resp. service (default)	Use all trips of all services of the alliance of the resp. service (only applicable if the service is part of an alliance)
Alliance	Use all trips of all carriers of the resp. alliance (only vessels where carrier is vessel operator)	Use all trips of all carriers from the resp. alliance (vessels where carrier is vessel operator and all services from carriers)	Use all trips of all services of the alliance (default)	Use all trips of all services of the alliance (default)

Identification of transshipments

Transshipments are required when no direct trips exist for the port pair, or when the identified direct route is deemed "unrealistic" due to significant detours. A "transshipment" is defined as the transfer of a container from one vessel to another vessel at an intermediate port.

The route identification relies on an algorithm that determines the most probable transshipment port from all possible options. The possible ports are identified via an analysis of all trips from the origin port and all trips to the destination port. A transshipment can take place if the list of "arrival ports" and "departure ports" contain an intermediate port match. For example, if vessels arrive at port C from port B, and depart from port A to port B, then port B is a potential transshipment port between A and C. Each potential transshipment port is assigned a score, and the port with the highest score is selected as the final transshipment port. The calculation of a port score is based on the following parameters derived from real vessel data from AXSMarine:

- Number of trips between the origin/destination and transshipment port
- Average lead time between the origin/destination and transshipment port
- Detour factor between shortest feasible distance (inclusive 15% distance correction factor) and an average real trip distance which includes the transshipment port (source Alphaliner).

If one transshipment port isn't sufficient, either because none can be found or the detour factor is too high, the algorithm will try to identify a second or even a third transshipment port. The calculation of the score for multiple transshipments applies the same scoring logic as for a single transshipment.

Table 59: Example of a transshipment score calculation for two possible transshipment ports

Possible transshipment ports	Trips	Lead time	Distances	Final Score
EEMUU - DEBRV **DEBRV – EGPSD**	65 trips 50 trips	6,4 days 14,9 days	Direct 8930 km Trips 8757 km	2,8957
EEMUU - NLRTM **NLRTM – EGPSD**	128 trips 54 trips	6,6 days 16,6 days	Direct 8930 km Trips 9283 km	2,5206

In this example, Bremerhaven (DEBRV) obtains the highest score and would be selected as a transshipment port. Please note that the algorithm also compares additional ports like Hamburg or Antwerp which are not shown in this example.

7.2.2 Transfer location identification

If the port is missing in the calculation request data, EcoTransIT World applies its transfer location identification, to bridge the gap and tranship the freight to an intermediate port from which it can be routed to the final destination. The determination takes into consideration all suitable ports around the origin and destination. Depending on the available trips between the selected nearby ports EcoTransIT World takes the most proper solution based on factors such as least needed transshipments, high frequency of vessel trips and low detour due to transshipments.

Port location areas

The trip information of AXSMarine includes the origin and destination port identified by UN/LOCODEs. A port`s UN/LOCODE reflects an entire port area consisting of more than a single UN/LOCODE. To avoid short feeder transfers between two UN/LOCODEs within a port area, EcoTransIT World maps defined UN/LOCODES to one or sometimes multiple UN/LOCODES that are linked to AXSMarine trips.

Table 60: Examples of UN/LOCODES within a port area

Port area location	All possible UN/LOCODE of the port area	AXS Marine accessible UN/LOCODE
Ningbo	CNBEI CNNBO CNZHH CNMSG CNMSN CNZOS CNNGB	CNNBG
Rotterdam	NLEUR NLMSV NLRZG NLROZ NLMSL NLBOT NLZBW NLVLA NLPER NLHIJ NLSCI NLWAL	NLRTM NLHVH
Sydney	AUSYD AUPBT	AUBTB
Tokio	JPHND JPOMA JPODT JPSBU JPCKU JPOGA JPSHK JPEGA JPUYA JPASI JPYOK JPHNN JPZAF JPNGI	JPTYO JPSHG JPICK JPKWS
Los Angeles/ Long Beach	USSPQ USTIY USWTN USOJL	USLAX USLGB

7.2.3 Ocean freight types, payload, and utilization

EcoTransIT World`s applied **freight types** and possible payloads include:

- Container freight
- Dry bulk
- Liquid bulk
- Vehicles (vessel type “RoRo” - Roll-on/Roll-off)
- General cargo (only available for small vessel sizes up to 5000 DWT[12] operating in coastal areas)

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12 Dead weight tonnage (DWT) is a measurement of a vessel’s carrying capacity. DWT includes cargo, fuel, fresh and ballast water, passengers and crew. Because the cargo load dominates the DWT of freight vessels, the inclusion of fuel, fresh water and crew can be ignored. DWT values correspond to specific draught definitions of a ship. The most commonly used and usually chosen if nothing else is indicated is the DWT at scantling draught, i.e the maximum structural draft of a ship (see e.g. https://en.wikipedia.org/wiki/Scantling).

The **maximum payload** per size class corresponds to

- The TEU-km-weighted average TEU capacity for the relevant size class of container freight
- For all other freight, 95% of the tkm-weighted average Dead Weight Tonnage (DWT) for the respective size class. The 95% value is an estimate based on the ratio of cargo capacity to DWT, using a sample of bulk carriers analysed in detail by the EcoTransIT World methodology team

Average DWT and TEU capacities are based on the Fourth IMO Greenhouse Gas Study [IMO, 2020].

Default **cargo utilization** by trade lane or vessel type/size class is listed in Table 61Table 62. Cargo utilization can by adjusted by the user.

Table 61: Default parameters used in EcoTransIT World per trade lane or vessel type/size class.

Vessel type (and cargo handling)	Trade lane / Size class	Days at sea at design speed	Design speed [km/h]	Default actual speed [km/h]	Default cargo utilization [%]
Bulk carrier (general)	Suez trade	181	28.0	21.7	66%
Bulk carrier (general)	Transatlantic	168	27.3	21.5	65%
Bulk carrier (general)	Transpacific	171	27.5	21.5	66%
Bulk carrier (general)	Panama	164	27.1	21.4	64%
Bulk carrier (general)	Other global	162	27.0	21.4	65%
Bulk carrier (general)	Intracontinental	145	25.5	20.4	68%
Container carrier	Suez	184	41.5	30.4	70%
Container carrier	Transatlantic	171	44.3	29.6	70%
Container carrier	Transpacific	173	44.3	29.9	70%
Container carrier	Panama	159	43.4	27.9	70%
Container carrier	Other global	168	43.3	29.0	70%
Container carrier	Intracontinental	166	42.8	28.6	70%
Container carrier	Intracontinental EU	170	44.2	29.5	70%
Great Lakes BC	Great Lakes	141	24.3	19.4	71%
Ferry / RoPax	World	125	26.4	19.2	60%
Ferry / RoPax	World	178	35.7	27.5	68%
General cargo	Coastal	135	20.6	16.3	66%
Bulk carrier	0 - <10'000 dwt	140	21.9	17.2	64%
Bulk carrier	10'000 - <35'000 dwt	141	25.6	20.4	64%
Bulk carrier	35'000 - <60'000 dwt	147	26.5	21.1	64%
Bulk carrier	60'000 - <100'000 dwt	169	26.7	21.1	64%
Bulk carrier	100'000 - <200'000 dwt	195	26.9	20.7	70%
Bulk carrier	>=200'000 dwt	209	27.0	21.9	72%
Chemical tanker	0 - <5000 dwt	132	22.6	17.8	84%
Chemical tanker	5000 - <10'000 dwt	148	23.9	19.1	84%
Chemical tanker	10'000 - <20'000 dwt	157	25.6	21.1	84%
Chemical tanker	20'000 - <40'000 dwt	166	27.2	22.4	84%
Chemical tanker	>=40'000 dwt	164	27.0	22.0	84%

Container carrier	0 - <1000 TEU	145	29.6	21.9	70%
Container carrier	1000 - <2000 TEU	148	35.2	24.8	70%
Container carrier	2000 - <3000 TEU	148	39.1	26.3	70%
Container carrier	3000 - <5000 TEU	157	42.8	27.2	70%
Container carrier	5000 - <8000 TEU	165	45.6	29.1	70%
Container carrier	8000 - <12'000 TEU	178	44.3	30.2	70%
Container carrier	12'000 - <14'500 TEU	168	44.1	30.2	70%
Container carrier	14'500 - <20'000 TEU	204	37.4	30.6	70%
Container carrier	>=20'000 TEU	169	37.6	30.2	70%
General cargo	0 - <5000 dwt	135	20.6	16.3	66%
General cargo	5000 - <10'000 dwt	136	23.5	18.1	66%
General cargo	10'000 - <20'000 dwt	156	25.9	21.1	66%
General cargo	>=20'000 dwt	156	27.8	22.0	66%
LNG tanker	0 - <50'000 cbm	157	26.3	21.7	68%
LNG tanker	50'000 - <100'000 cbm	197	30.4	26.1	73%
LNG tanker	100'000 - <200'000 cbm	213	35.2	27.6	73%
LNG tanker	>=200'000 cbm	210	35.6	29.6	73%
Oil tanker	0 - <5000 dwt	103	21.1	16.1	59%
Oil tanker	5000 - <10'000 dwt	107	22.4	16.9	59%
Oil tanker	10'000 - <20'000 dwt	103	23.9	18.1	59%
Oil tanker	20'000 - <60'000 dwt	127	27.0	20.7	59%
Oil tanker	60'000 - <80'000 dwt	152	27.4	21.5	59%
Oil tanker	80'000 - <120'000 dwt	148	27.4	20.7	59%
Oil tanker	120'000 - <200'000 dwt	166	28.0	21.1	59%
Oil tanker	>=200'000 dwt	193	28.7	22.0	59%
Liquid tanker	0 - <1000 dwt	77	17.8	13.9	55%
Liquid tanker	>= 1000 dwt	177	25.2	21.5	55%
Ferry / RoPax	0 - <2000 gt	114	24.1	16.7	50%
Ferry / RoPax	2000 - <5000 gt	109	32.2	21.1	50%
Ferry / RoPax	5000 - <10'000 gt	95	40.0	24.4	50%
Ferry / RoPax	10'000 - <20'000 gt	141	37.6	28.0	50%
Ferry / RoPax	>=20'000 gt	160	41.9	30.6	50%
Refrigerated bulk	0 - 2000 dwt	111	22.4	16.9	50%
Refrigerated bulk	2000 - <6000 dwt	113	27.2	20.6	50%
Refrigerated bulk	6000 - <10'000 dwt	117	32.2	25.2	50%
Refrigerated bulk	>=10'000 dwt	176	37.4	30.2	50%
RoRo carrier	0 - <5000 dwt	93	20.7	15.0	70%
RoRo carrier	5000 - <10'000 dwt	162	32.6	26.3	70%
RoRo carrier	10'000 - <15'000 dwt	172	36.3	28.7	70%
RoRo carrier	>=15'000 dwt	158	35.4	28.2	70%
RoRo carrier	0 - <30'000 gt	167	32.0	25.2	70%
RoRo carrier	30'000 - <50'000 gt	192	35.9	27.2	70%
RoRo carrier	>= 50'000 gt	219	36.9	28.7	70%

7.3 GHG activities (ocean)

7.3.1 Energy consumption (ocean)

Available energy consumption calculation methods

EcoTransIT World calculates the energy consumption of ocean transports using two different methods EcoTransIT:

- All ocean vessels: bottom-up, based on the methodology used in the Fourth IMO Greenhouse Gas Study from 2020 [IMO, 2020]. This method allows accounting for the impact of speed on fuel consumption and emissions, through practices such as "slow steaming" to save fuel.
- Default for container vessels: top-down, by deriving energy consumption from the CO_2 emission factors by trade lane, published annually by Clean Cargo (CC) based on measured fuel consumption of its members [SFC, 2024].

IMO-based methodology (bottom-up approach)

Following a bottom-up approach in this method the energy consumption is calculated separately for main engine, auxiliary engine, and boiler, aligned with the methodology used in the Fourth IMO Greenhouse Gas Study from 2020 [IMO, 2020]. The calculation is carried out at the aggregation level of vessel type and size class as indicated in [IMO, 2020] (see Table 81 in Annex N for vessel types and associated parameters).

To account for emissions during cargo handling at ports and on return journeys, fuel consumption is separately modelled for the main engine, auxiliary engine, and boiler over a hypothetical one-year period. In case of reduced vessel speed, the vessel's activity extends the one-year period to deliver the same transport services (see Chapter 7.5.1).

Cargo weight has only a minor impact on the overall energy consumption of vessels. This is because vessels must maintain a certain draft for safety reasons, which is regulated by taking in or discharging ballast water. Additionally, fuel consumption is primarily influenced by other factors - most notably wave and wind resistance. Wave resistance exponentially increases with speed, making speed one of the most important factors.

The **power demand** in kWh/tkm **of the main engine** is determined using the following formulas. First, the power demand is calculated using the so-called "admiralty formula" [IMO, 2020]:

$$W_{ME,Ship} = \frac{CF_{Ship} * W_{REF} * \left(\frac{t}{t_{REF}}\right)^{0.66} * \left(\frac{v}{v_{REF}}\right)^{3}}{CF_{Weather} * CF_{Fouling}}$$

With:

$W_{ME,Ship}$	=	Propulsive power demand of the main engine in kW
W_{REF}	=	Rated average main engine power at MCR [kW] (Table 81 in Annex N [IMO, 2020])
t, t_{REF}	=	Actual draught and design draught of the ocean vessel. Since no data on actual draught is available, EcoTransIT World assumes a ratio of both equals 1 EcoTransIT.
v, v_{REF}	=	Actual speed and design speed of the vessel. The actual speed can be adapted by EcoTransIT World users in the web application.
CF_{Ship}	=	Vessel-specific correction factor. See Table 44 in [IMO, 2020]. For large container carriers, this is partially calibrated to better match the fuel consumption reported by Clean Cargo members.
$CF_{Weather}$	=	Correction factor for weather condition impacts (wind, waves). See Table 44 in [IMO, 2020].
$CF_{Fouling}$	=	Correction factor for the influence of hull fouling/hull roughness. See Table 44 in [IMO, 2020].

The result of the above equation is divided by the speed in km/h to obtain kWh/km, and by the cargo mass to obtain kWh/tkm:

$$W_{ME,tkm} = \frac{\frac{W_{ME,Ship}}{v}}{(CC * CU)}$$

With:

$W_{ME,tkm}$	=	Propulsive power demand of the main engine in kWh/tkm
CC	=	Cargo capacity of the vessel. By default, DWT * 0.95
CU	=	Average capacity utilization of the vessel in %, based on [IMO, 2009, 2020], and Clean Cargo [SFC, 2024]

The **power demand** in kWh/tkm **of auxiliary engine and boiler** is calculated as follows:

$$W_{A,B} = \frac{\left(\left((d_{sea} * 24 * L_{sea}) + (d_{port} * 24 * L_{port})\right) * n\right)}{(Dist * CC * CU)}$$

With:

$W_{A,B}$	=	Power demand of the auxiliary engine or boiler in kWh/tkm
d_{sea}	=	Number of days at sea per year [IMO, 2020]
L_{sea}	=	Auxiliary engine/boiler load at sea [kW] [IMO, 2020]
d_{port}	=	Number of days in port per year
L_{port}	=	Auxiliary engine/boiler load in port [kW], [IMO, 2020]
n	=	Number of auxiliary engines/boilers [IMO, 2020]
$Dist$	=	Annual distance driven by the vessel, estimated as d_{sea} * 24 * v

Energy consumption is calculated based on power demand for main engine, auxiliary engines and boilers as follows:

$$EF_{FT,MT} = \sum_{FT,AG} Sh_{AG} * W_{MT,OA} * SFC_{FT,AG,MT,ET} * \frac{EF_{FT,ET,MT}}{1000}$$

With:

$EF_{FT,MT}$	=	Energy consumption in MJ/tkm for fuel type FT and machine type *MT* (i.e. main engine/auxiliary engine/boiler)
FT	=	Fuel/technology type (see Table 62)
OA	=	operation area (at sea or in port)
AG	=	Age group: For specific fuel consumption (i.e. engine efficiency), the following age groups ("generations") are differentiated: - Engines built before 1983 - Engines built 1984-2000 - Engines built from 2001 onwards
ET	=	Engine type (for diesel engines): SSD (Slow speed diesel), MSD (medium speed diesel), and HSD (high speed diesel). Vessel types with up to 15 MW average rated main engine power are assumed to be equipped with MSD (medium-speed diesel) main engines and for larger vessels are assumed to be equipped with SSD (slow-speed diesel) engines based on [Williams et al., 2008].
Sh_{AG}	=	Share of vessels in age group *AG*. The share by age group is calculated based on the build years of each age group or "generation" (see above), the current reference year, and cosine-shaped age distributions assuming a life expectancy of up to 50 years for vessels < 50'000 DWT and a life expectancy of up to 30 years for vessels >=50'000 DWT (see also [FOEN, 2015])
$W_{MT,OA}$	=	Power demand of machine type *MT* (i.e. main engine/auxiliary engine/boiler) in operation area *OA* (at sea/in port) in kWh/tkm
$SFC_{FT,AG,MT,ET}$	=	Specific fuel consumption of engine type *ET*, machine type *MT* with fuel/technology type *FT* and in age group *AG*. See Table 19 in [IMO, 2020]. Specific fuel consumption factors for blended fuels are derived from the HFO factors based on the ratio of their energy content to the one of HFO (see Table 62).
$EF_{FT,ET,MT}$	=	Energy content of for fuel type FT, engine type *ET*, and machine type *MT* in MJ/kg (see Table 14 for EU fuels/rest of the world and Table 21 for US fuels).

Appliance for vessel shares identified via AIS-data (AXSMarine)

EcoTransIT World determines the vessel category class for each trip from the vessel size (max. DWT or max. container) (compare chapter 7.1). All individual emission results are weighted according to the maximum TEU or DWT capacity of the respective vessels.

Clean Cargo methodology

Clean Cargo is a collaborative initiative for container shipping led by the Smart Freight Centre (SFC), bringing together ocean cargo carriers, freight forwarders, and cargo owners. Clean Cargo focuses on tracking and reducing greenhouse gas emissions from container shipping and sharing ocean container freight decarbonization best practices.

Within this scope, Clean Cargo provides a standardized methodology for calculating and reporting CO_2e emissions per TEU-kilometre across trade lanes or port pairs broken down per carrier.

These emission intensity values are calculated based on:

- Fuel Consumption Data, based on actual fuel used by the Clean Cargo Carriers.
- Emission Factors: Clean Cargo fuel emission factors are applied to convert fuel consumption into CO_2e emissions [SFC, 2024].
- Distance and Capacity Utilization: Emissions are assigned based on the distance travelled and the utilization of cargo capacity, expressed in TEU per kilometre.

Based on the Clean Cargo intensity values EcoTransIT World first back calculates the energy provision, and then calculates all other emissions, using its standard energy-based bottom-up approach. Energy calculation using the intensity values is based on following values:

- General fuel mixes of the vessels within and outside of ECA areas. These fuel mixes are updated annually and consist of analyses of Clean Cargo data
- Emission factors to convert CO_2e into megajoule. These factors are aligned with the factors used within Clean Cargo. These factors are also used later in bottom-up calculation and can differ from the standard emission factors of EcoTransIT World.

Only EcoTransIT World users that are Clean Cargo members are allowed to use the carrier differentiated intensities and port pair methodology. For other users the average emission intensity values per trade lane are applied to calculate the emissions.

Clean Cargo is the recommended accounting method in EcoTransIT World for containerized ocean shipments.

Operational fuel mix

The fuel types differentiated in vessel operational energy consumption and emission calculation of ocean transports in EcoTransIT World are listed in Table 62.

As indicated by the multiple abbreviations in the first column of Table 62, the EcoTransIT World maritime fuel classification simplifies the diverse fuels landscape introduced by the “IMO 2020” regulation [IMO, 2019]. This simplification is necessary due to limitations in the granularity and quality of available data on ocean vessel fuel consumption.

Which fuel is used, varies among other factors, by the vessel operating area, namely Emission Control Areas (ECAs) or by individual port. Chapter 7.5.2 details which ocean areas, and Chapter 7.5.4 describes which ports are affected in which way.

The shares of total vessel energy consumption given in the last two columns of Table 62 are valid for the year 2022 and are given as an example. With the introduction of the “IMO 2020” regulation by the International Maritime Organization [IMO, 2019] – which either limits the allowed amount of sulphur in maritime fuels to 0.5%, or mandates the use of a scrubber to reduce sulphur emissions – fuel mixes changed drastically in 2020 and have been gradually adjusting since then. EcoTransIT World uses the most recent available fuel mix data based on Clean Cargo fuel consumption data. Optionally, users can specify their own fuel mix (“energy composition”) from the fuels listed in Table 62 (new feature available from 2026). For each trip, the distance share inside/outside ECAs, as well the energy-based shares of different vessel technologies is considered - unless the route uses individual ship data with specified vessel technologies.

Table 62: Fuel types and sulphur (S) emission reduction technologies considered in EcoTransIT World for sea transport, along with the shares of fuel consumption in the year 2024. For further fuel properties such as energy contents or CO_2(e) emission factors, please refer to Table 14 (EU fuels/rest of the world) and Table 21 (US fuels).

Fuel type (refer Tables 14,21)	Other terms and included fuel types	S reduction technology	S content in fuel	Energy share in 2024	
				Inside ECA	Outside ECA
HFO	HFO (Heavy fuel oil; includes HSFO, HSHFO)	Scrubber	2.60%	32.6%	32.9%
		No Scrubber	2.60%	0.0%	1.8%
VLSFO	Blends, hybrid fuels, LFO, LSFO	none	0.50%	0.0%	48.8%
ULSFO	MDO, MGO (ECA-compliant fuels with max. 0.1% S)	none	0.07%	65.3%	14.5%
LNG	Liquefied natural gas	none	0%	2.1%	2.1%

Onboard electricity consumption

Ocean vessels use their auxiliary engines and steam boilers to generate the electricity used on board, including during port stays. The air pollutant emissions resulting from vessel at port have a significant impact on the air quality in affected port surroundings. That is why, more and more ports are starting to offer onshore power supply (OPS); however, currently their number is still low – 10 to 30 ports in Europe, depending on the source, plus a handful in the USA and Canada ([EEA, 2024; World Port Sustainability Program, 2024]); in the ports providing OPS, it may not be available on all terminals. Regardless of the port’s infrastructure the vessels themselves need to be technically ready (i.e. fitted with the required connections) to be able to use OPS – this is estimated to be the case for about 25% of container vessels by 2025 [HPA, 2021].

EcoTransIT World currently does not explicitly consider OPS. The energy consumption during port stays, which could theoretically be replaced by OPS, accounts for approx. 1 – 4% of the total energy consumption of large container vessels and bulk carriers (estimated based on the bottom-up energy consumption calculation methodology described above). EcoTransIT World currently assumes this energy consumption to be covered by HFO or ULSFO, MDO or MGO (depending on whether the port is in an ECA. At present, only a negligible portion of vessel energy consumption is replaced by OPS, constrained by the limited overlap between OPS-equipped terminals and OPS-ready vessels.; Although precise data is unavailable, it can be stated with high confidence that the current impact on overall vessel energy consumption and associated GHG emissions is minimal. The power supply from OPS is not emission-free either, as it depends on the electricity mix at the respective port. In conclusion, EcoTransIT the absence of explicit consideration of OPS in EcoTransIT World leads to a negligible overestimation of energy consumption and GHG emissions.

7.3.2 Methane emissions (ocean)

Methane slip is accounted for in the CH_4 emission factors based on the Fourth IMO Greenhouse Gas Study from 2020 [IMO, 2020] EcoTransIT (see Chapter 7.4). As reflected in these emission factors, SSD engines (slow speed engines, in use on larger vessels) operating on LNG emit 250 times as much CH_4 as those running on HFO or ULSFO; for MSD engines (medium-speed engines, in use on smaller vessels), the factor is even 550 (see Table 55 in [IMO, 2020]).

7.3.3 Refrigerants (ocean)

Reefer containers are usually transported in intermodal transports, thus, refrigerant losses for cooled ocean transports are handled like those for truck reefers. A description of how the refrigerant losses for reefers were derived is found in chapter 5.3.2. Refrigerant losses of cooled reefers for sea vessels are not yet included into EcoTransIT World (the additional energy consumption and GHG emissions are accounted for via the Clean Cargo emission intensity factors, [SFC, 2024].

7.4 Air pollutant operational emissions (ocean)

Fuel emission factors in EcoTransIT World are based on the Fourth Greenhouse Gas Study of the International Maritime Organization [IMO, 2020]. As a result, EcoTransIT World differentiates between "fuel-based" and "energy-based" pollutants.

The emissions of the **"fuel-based" pollutants** depend primarily on fuel type and quality. They include CO_2 and SO_x. The calculation of the emission intensity factors in g/tkm is comparable to the bottom-up calculation of fuel/energy consumption (see Chapter 7.3.1):

$$EF_{FT,MT} = \sum_{FT,AG} Sh_{AG} * W_{MT,OA} * SFC_{FT,AG,MT,ET} * EF_{FT,ET,MT}$$

With:

$EF_{FT,MT}$	=	Emission factor in g/tkm for fuel type FT and machine type *MT* (i.e. main engine/auxiliary engine/boiler)
FT	=	Fuel/technology type (see Table 62)
OA	=	operation area (at sea or in port)
AG	=	Age group: For specific fuel consumption (i.e. engine efficiency), the following age groups ("generations") are differentiated: - Engines built before 1983 - Engines built 1984-2000 - Engines built from 2001 onwards
ET	=	Engine type (for diesel engines): SSD (Slow speed diesel), MSD (medium speed diesel), and HSD (high speed diesel). Vessel types with up to 15 MW average rated main engine power are assumed to be equipped with MSD (medium-speed diesel) main engines and for larger vessels are assumed to be equipped with SSD (slow-speed diesel) engines based on [Williams et al., 2008].
Sh_{AG}	=	Share of vessels in age group *AG*. The share by age group is calculated based on the build years of each age group or "generation" (see above), the current reference year, and cosine-shaped age distributions assuming a life expectancy of up to 50 years for vessels < 50'000 DWT and a life expectancy of up to 30 years for vessels >=50'000 DWT (see also [FOEN, 2015])
$W_{MT,OA}$	=	Power demand of machine type *MT* (i.e. main engine/auxiliary engine/boiler) in operation area *OA* (at sea/in port) in kWh/tkm
$SFC_{FT,AG,MT,ET}$	=	Specific fuel consumption of engine type *ET*, machine type *MT* with fuel/technology type *FT* and in age group *AG*. See Table 19 in [IMO, 2020]. Specific fuel consumption factors for blended fuels are derived from the HFO factors based on the ratio of their energy content to the one of HFO (see Table 62).
$EF_{FT,ET,MT}$	=	Base emission factor in g/g fuel for pollutant *p*, engine type *ET* and machine type *MT*.

Sources: CO_2: See Table 62, SO_x: Converted from S content in Table 62 to g/g using eq. 15 in [IMO, 2020]. For the fuel/technology type HFO with scrubber, we assume a reduction of 96% of SO_x emissions compared to HFO use without scrubber based on [Yang et al., 2017].

Emissions of the **"energy-based" pollutants**, on the other hand, primarily depend on the combustion processes in the engine, which are load-dependent to a large degree; their base emission factors are indicated in g/kWh and those covered by EcoTransIT World include NO_x, NMVOC and PM. Their emission intensity factors in g/tkm are calculated using the following equation:

$$EF_{p,MT,a} = \sum_{FT,AG} Sh_{FT,a} * Sh_{AG} * W_{MT,OA} * EF_{p,FT,ET,MT,AG}$$

With:

AG = Age group: For PM, base emission factors are differentiated by the same "generations" as specific fuel consumption (see above).
For NO_x, the following IMO Tiers are differentiated:

- Tier 0: Vessels built before 2000
- Tier 1: Vessels built 2000-2010
- Tier 2: Vessels built 2011-2015
- Tier 3: Vessels built from 2016 onwards

$EF_{p,FT,ET,MT,AG}$ = Base emission factor for pollutant *p*, engine type *ET*, machine type *MT* and, in the case of PM and NO_x, age group *AG*.

Sources: NO_x: Table 23, [IMO 2020], NMHC: Tables 61 and 62 in Annex M [IMO, 2020], PM: Tables 52-54 in Annex M [IMO, 2020]

7.5 Specialties

7.5.1 Consideration of speed

Vessel speed is one of the most critical parameters in the calculation of fuel consumption and emissions for sea transport. Due to the over-proportional reduction in fuel consumption compared to the service speed, "slow steaming" is a widespread practice in sea transport – in 2012, the average ratio of operating speed to design speed was 75% [IMO, 2015] and it has since remained within the same order of magnitude. Cargo utilization is likewise critical as EcoTransIT World calculates shipment-specific emissions, which decrease as the emissions are spread over more goods.

By default, the operating speed is determined by trade lane and corresponds to the tkm-weighted averages per IMO vessel type and size class [IMO, 2009, 2015, 2020]. Optionally, users can individually adjust speed and cargo utilization as needed. The speed adjustment is expressed in percent reduction relative to the chosen vessel's design speed.

Regardless of whether the inputs are default or user-specified, the fuel consumption and emission factors in EcoTransIT World are adjusted based on the equations described in the following paragraph.

The main engine load is adjusted based on the speed reduction relative to design speed (based on [IMO, 2020], leaving out the absolute rated power of the vessel from the "admiralty formula" presented in Chapter 7.3.1:

$$LF_{act} = \frac{CF_{Ship} * \left(\frac{v}{v_{REF}}\right)^3}{CF_{Weather} * CF_{Fouling}}$$

With:

LF_{act}	=	Load factor of the main engine resulting from user-defined speed settings
v, v_{REF}	=	Actual speed and design speed of the vessel.

Once the engine load under the actual speed is known, the fuel consumption and emission factors are adjusted. The adjustment is carried out according to the following formula. It adds up the fuel consumption (or emissions, respectively) of the main engine, the auxiliary engine and the boiler, and accounts for adjustments of air pollutant emission intensity factors for low load, as well as for the additional time at sea due to slower speed:

$$EF_{adj} = (EF_M * LF_{act} * LAF) + \left(EF_{A.Sea} + EF_{B,Sea}\right) * (1/(1 - v/v_{REF})) + (EF_{A,Port} + EF_{B,Port})$$

With:

EF_{adj}	=	Speed-adjusted fuel consumption or emission factor [g/tkm]
EF_M	=	Fuel consumption or emission factor of the main engine [g/tkm]
LAF	=	Low-load adjustment factor for air pollutants: Inter-/extrapolated based on factors for given load points and pollutants in Table 20 in [IMO, 2020]
$EF_{A.Sea}$	=	Fuel consumption or emission factor of the auxiliary engine at sea [g/tkm]
$EF_{B.Sea}$	=	Fuel consumption or emission factor of the boiler at sea [g/tkm]
$EF_{A.Port}$	=	Fuel consumption or emission factor of the auxiliary engine in port [g/tkm]
$EF_{B,Port}$	=	Fuel consumption or emission factor of the boiler in port [g/tkm]

7.5.2 Adjustment of cargo utilization

Optionally, users can adjust the default cargo utilization in Table 61. Energy/fuel consumption and emission intensity factors are adjusted for the deviation of cargo utilization from the default using:

$$EF_{final} = EF_{adj} * (CU_{Def}/CU_{act})$$

With:

EF_{final}	=	Cargo utilization-adjusted final fuel consumption or emission intensity factor [g/tkm]
CU_{Def}	=	Default cargo utilization ([IMO, 2009], tkm-weighted average for the respective trade lane or EcoTransIT World vessel type and size; see Table 61) [%]
CU_{act}	=	Actual cargo utilization [%]

7.5.3 IMO Emission Control Areas (ECAs)

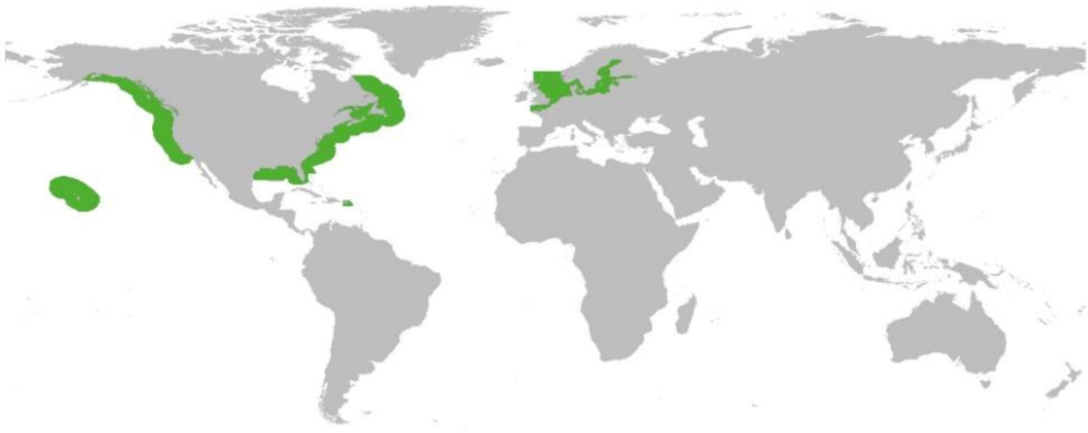
Emissions from ocean vessels are regulated in Annex VI of the “International Convention on the Prevention of Pollution from Ships”, also known as MARPOL. Annex VI defines two sets of emission and fuel quality requirements: on one hand global requirements, and on the other hand more stringent requirements applicable in so-called Emission Control Areas (ECAs). An ECA can be designated for SO_x, PM, or NO_x, or all three pollutants, subject to a proposal from a Party to Annex VI. For NO_x, the date of entry into effect only applies to vessels constructed after that date, while for SO_x and PM, all vessels must comply from the date of entry into effect. This difference is because SO_x and PM emissions mainly depend on the sulphur content of the fuel - which is switchable on existing vessels - whereas NO_x reduction requires a new or upgraded engine.

Existing Emission Control Areas include[13]:

- Baltic Sea (SO_x in effect from 2006, NO_x in effect from 2021)
- North Sea (SO_x, in effect from 2007, NO_x from 2021)
- North American ECA, including most of US and Canadian coast (SO_x, and PM in effect from 2012, NO_x from 2016).
- US Caribbean ECA, including Puerto Rico and the US Virgin Islands (SO_x, and PM in effect from 2014, NO_x from 2016).

13 https://www.imo.org/en/OurWork/Environment/Pages/Special-Areas-Marpol.aspx

Figure 16: Global existing Emission Control Areas



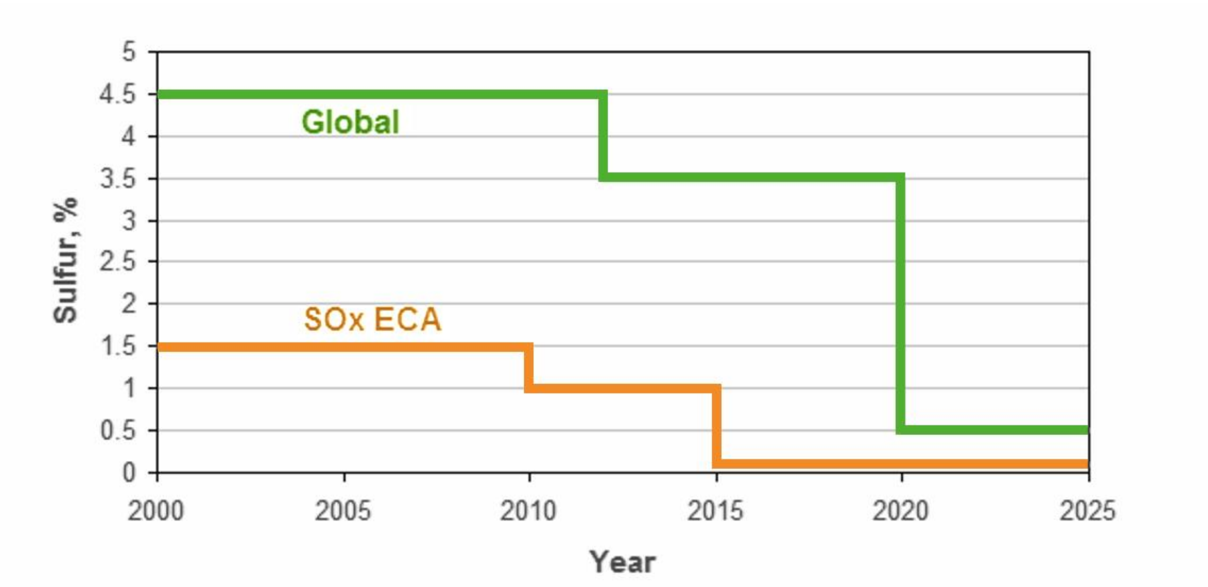
Sources: EcoTransIT World, IVE

The fuel sulphur limits inside and outside ECAs are depicted in Figure 17.

Different options exist to comply with the emission limits in ECAs. Currently the most widespread is to use ULSFO (ultra-low sulphur fuel oil) or MDO/MGO, which has a sulphur content of 0.1% (compare Table 62). Other options are to use a scrubber, an after-treatment technology, use sink sea water to wash SO_2 out of the exhaust gas, or to switch to LNG instead of maritime diesel. The latter two options are less widespread: as of 2020, approximately 14% of container vessels were fitted with scrubbers [ICCT, 2021] and about 1.3% of energy use in ECAs was accounted for by LNG (own analysis of Clean Cargo data).

EcoTransIT World accounts for the impact of ECAs on emissions by using the respective fuel mixes inside/outside ECAs (Table 62).

Figure 17: MARPOL Annex VI fuel sulphur limits [Dieselnet, 2016].



Source: [Dieselnet, 2016]

7.5.4 Air pollution regulations in ports

Besides ECAs (see chapter above), stricter emission limits also apply to certain ports, for example all ports in Europe and California. Ports in other parts of the world have voluntary fuel switch programs, which offer incentives like reduced port fees for using lower-sulphur fuels. The maximum allowed sulphur level in these programs varies. For simplicity it can be assumed that ULSFO or MGO/MDO (with max. 0.1% sulphur content) is used in ports with stricter emission limits or voluntary fuel switch programs, such as:

- All ports in Europe
- All ports in California
- Seattle, New York, New Jersey, Houston (USA)
- Vancouver (Canada)
- Hong Kong
- Singapore

7.6 Allocation in ferry transport

Ferry transport is a special case within EcoTransIT World as it represents a “hybrid” mode of transport, for example if for trucks or even trains transport on a vessel. EcoTransIT World handles ferry routes as an extension of the road and rail network. The user of the web interface cannot choose “ferry” as a transport mode, but ferry transport is chosen automatically when the mode is road or rail, and the best-suited route leads via a ferry route (compare Chapter 3.4). Optionally, the user can choose whether ferry routs should explicitly avoid or preferred. The description of ferry transport is placed in the sea transport chapter in this report since the basic methodology and source of the pollutant emission factors is the same as for sea transport.

The allocation of energy consumption between passenger and freight transport is a sensitive and controversial issue. Different allocation methods have been proposed (e.g. [H. Kristensen, 2000; Kusche, 2000]); the decision which one is the most appropriate cannot be made objectively but remains a convention. EcoTransIT World currently allocates the energy consumption to freight based on the proportion of deck area designated for vehicles and passengers; this allocation method is compliant with the European norm (EN) 16258. ISO 14083 specifies an allocation method based on passenger equivalents of vehicles in Appendix Chapter G.4.3, which is planned for implementation in EcoTransIT World in near future.

The fuel consumption per gross tonne-kilometre of cargo (i.e. allocated to each tonne of cargo inside the ferry including the vehicle, i.e. train or truck, in g/tkm) is calculated based on the following equation:

$$FC_{cargo,gross} = \left(\left(FC_{Ferry} \times S_{Freight}\right)/(CC \times CU)\right)$$

All input parameters for this equation were derived from two studies from the Baltic and Mediterranean Seas, i.e [H. O. H. Kristensen and Hagemeister, 2011; Scandria, 2012]. Their values are displayed in Table 63**.**

Table 63: Parameters for the calculation of final fuel consumption of cargo on ferries.

Parameter	Description	Unit	Value
FC_{cargo}	Final fuel consumption per gross tonne kilometre	g/tkm	14.1
FC_{Ferry}	Total fuel consumption of the ferry (main and auxiliary engines)	g/km	86,971
$S_{Freight}$	Share of freight in terms of deck area dedicated to vehicles	%	54
CC	Cargo capacity of the ferry [t]	t	5,218
CU	Cargo capacity utilization of the ferry	%	64

The fuel consumption per net tonne-kilometre (based only on the weight of goods) is calculated by dividing the fuel consumption per gross tonne-kilometre by the ratio of goods weight to total vehicle weight, including the goods transported:

$$FC_{cargo,net} = FC_{cargo,gross}/\left(m_{cargo}/m_{(vehicle+cargo)}\right)$$

where:

$FC_{cargo,net}$= final fuel consumption per net tonne kilometre [g/tkm]

$FC_{cargo,gross}$= final fuel consumption per net tonne kilometre [g/tkm]

m_{cargo}= mass of cargo on the vehicle (truck, train) [t]

$m_{(vehicle+cargo)}$ = mass of the vehicle (truck, train) including cargo [t]

The same pollutant emission factors in g/g fuel based on [IMO, 2015] are used for ferries as for other sea transport (see Chapter 7.4), assuming a share of 65% of the main engine in total fuel consumption (based on [IMO, 2015]).

8 Rail transport

8.1 Rail freight Transport Operation Categories (TOCs)

The main indicator for calculating energy and emissions of rail transport is the energy consumption of the total train depending on the gross tonne weight of the train and the relation of net tonne weight to gross tonne weight. In EcoTransIT World this was taken into consideration by using different general train types, defined by the gross tonne weight of the train and different freight types (average, bulk, volume). In addition to this general approach, the current version of EcoTransIT World allows to use special train types for dedicated transport tasks.

General train types

European railway companies have 1,000 t as a typical average gross weight for international trains [UIC, 2009]. The maximum gross weight for international traffic is up to 2,000 tonnes. In several countries outside Europe the typical gross tonne weight is significantly higher e.g. in Australia, Canada, China or the US. Typical train weights in these countries are about 4,000 tonnes and more. For this reason, EcoTransIT World must cover a wide range regarding train weight.

Table 64: Definition of general train types in EcoTransIT World

Train type	Gross tonne weight train	Empty weight wagon	Capacity wagon	Load factor (LF)	Empty trip factor (ETF)
Light	500 t	23 t	61 t	Volume: 30%	Volume: 20%
Average	1000 t	23 t	61 t	Average: 60%	Average: 50%
Large	1500 t	23 t	61 t	Bulk: 100%	Bulk: 80%
Extra Large	2000 t	23 t	61 t	Bulk: 100%	Bulk: 80%
Heavy	5000 t	23 t	61 t	Bulk: 100%	Bulk: 80%

Source: ifeu assumptions

Train types for dedicated transport tasks

For dedicated freight transports (cars, container, several solid bulks and liquids), special trains and wagon types are used. Typical train configurations come from transport statistics of major railway companies (DB Schenker and SNCF) from the year 2012. EcoTransIT World uses average values for these train types. They mainly reflect the European situation.

Table 65: Definition of dedicated train types in EcoTransIT World

Train type	Gross tonne weight train	Empty weight wagon	Capacity wagon	Load factor (LF)	Empty trip Factor (ETF)
Car	700 t	28 t	21 t	85%	50%
Chemistry	1200 t	24 t	55 t	100%	100%
Container	1000 t	21 t	65 t	48%	20%
Double Container	2500 t	25 t	100 t	48%	20%
Rolling Road - Truck	1200 t	25.4 t	70 t	42%	20%
Rolling Road - Semi Trailer	1200 t	34.3 t	100.7 t	47%	20%
Rolling Road - Swap Body	1200 t	34.3 t	100.7 t	39%	20%
Coal and steel	1700 t	26 t	65 t	100%	100%
Building materials	1200 t	22 t	54 t	100%	100%
Manufactured products	1200 t	23 t	54 t	75%	60%
Cereals	1300 t	20 t	63 t	100%	60%

Source: ifeu assumptions based on information from DB Cargo and SNCF

8.2 Rail freight transport activity

8.2.1 Rail distance calculation

The determination of a railway route is based on the EcoTransIT World internal routing (compare chapter 3.4.1) which considers the attributes electrified or diesel line and freight corridor (only within Europe). Depending on the selected train parameters these attributes are considered as resistance within the routing algorithm. For example, if a train is specified as electrified, the routing prefers routes with tracks that are electrified. However, diesel tracks can also be used in this case, but these have a higher resistance and are only considered if an electrified track would cause a four times higher detour or if an electrified track is not available at all.

The freight corridor attribute simulates railway highways for freight trains. Tracks with this attribute are preferred and have a lower routing resistance compared to regular tracks.

Table 66: Resistance for attributes within the railway network

Attribute	Resistance
Freight corridor	1,0
Non-freight corridor	1,8
Diesel tracks at electrified calculation	4,0

There are also ferry connections within the rail network. These ferry routes are modelled like virtual tracks, with the entire train being placed on the ferry. EcoTransIT World has various built-in resistances for ferry routes which can be specified within the calculation request.

Table 67: Resistance for ferries within railway network

Ferry handling	Resistance
Standard	5,0
Preferred	1,0
Obstruct	100,0
Deny	∞

8.2.2 Transfer location identification for rail shipments

If no railway station (UIC – International Union of Railways code) is specified directly within the calculation request EcoTransIT World applies its transfer location identification where the freight can be transhipped to a train.

Distance-based method (Nearest-by)

With the nearest-by method (default), a transfer point is identified by selecting the geographically closest UIC-coded location to the origin or destination. This approach is purely distance-based and does not assess whether the selected station has a relevant role in freight handling or forms part of a realistic combined transport chain. To achieve a more accurate representation of actual transport processes, it is therefore recommended to explicitly specify relevant transfer locations, such as intermodal or container terminals, within the transport chain description.

Importance based method

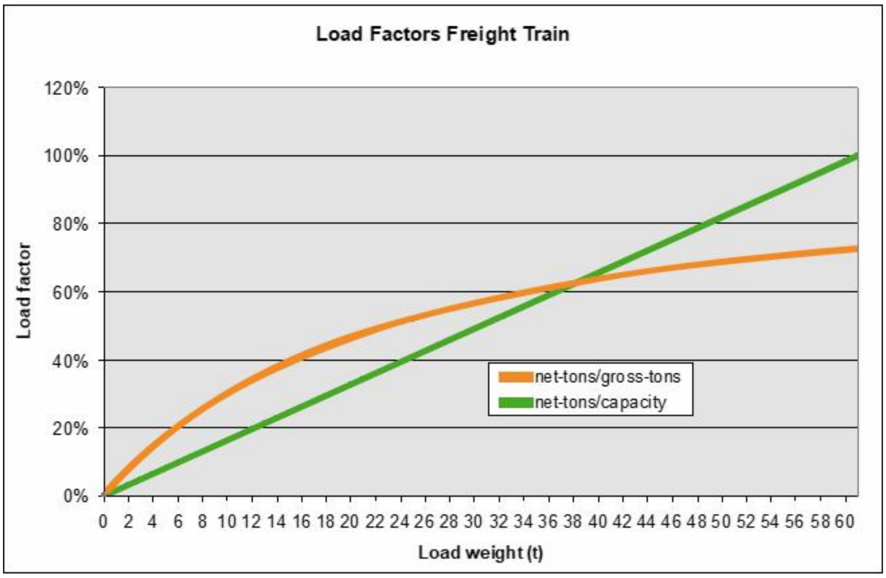
This method extends transfer point identification by incorporating a qualitative assessment of railway stations. Instead of relying solely on distance, UIC codes are evaluated based on their “freight handling relevance”. Therefore, all UIC codes in EcoTransIT World are enriched with a corresponding parameter. A higher value increases the likelihood that a station will be selected, even if this requires accepting a certain detour.

The objective of this method is to preferentially identify railway stations located close to intermodal terminals, thereby reflecting realistic combined transport operations. The classification of terminal proximity is based on data from the SGKV[14]. As a result, the generated transport chains are more closely aligned with real-world freight transport practices.

8.2.3 Rail freight types (payload and utilization)

The load factor for trains is originally defined as the relation of net tonnes/gross tonne. For a better comparison with road and sea transport the values are transformed to the relation freight load/capacity. The following figure shows a comparison of the load factors for freight trains, based on the average wagon defined in EcoTransIT World (see Table 64: empty weight: 23 tonnes, payload capacity: 61 tonnes).

Figure 18: Load factors for freight trains



Payload capacity

The limiting factor for payload capacity of a freight train is the axle load limit of a railway line. International railway lines normally are dimensioned for more than 20 tonnes per axle (e.g. railway class D: 22.5 tonnes). Therefore, the payload capacity of a freight wagon must be stated as convention.

In railway freight transport a high variety of wagons are used with different sizes, for different cargo types and logistic activities. However, the most important factor influencing energy consumption and emissions is the ratio between the payload and the total weight of the wagon. In EcoTransIT World, a typical average wagon is defined based on wagon class UIC 571-2 (ordinary class, four axles, type 1, short, empty weight 23

[14] https://sgkv.de/en/portfolio/ct-tools/intermodal-map/

tonnes, [Carstens, Stefan and Diener, Hans Ulrich, 2000]). The payload capacity of 61 tonnes was defined by railway experts of the EcoTransIT World Initiative (EWI). The resulting maximum total wagon weight is 84 tonnes and the maximum axle weight 21 tonnes. It is assumed that this wagon can be used on all railway lines worldwide. In EcoTransIT World, the standard railway wagon is used for the general train types (light, average, large, extra-large and heavy).

For dedicated freight transports (cars, containers, several solid bulks and liquids), special wagon types are used. Empty weight and payload capacity for these wagon types come from transport statistics of major railway companies (DB Schenker, SNCF, Geodis from 2012). EcoTransIT World uses average values for these special wagon types.

All values for empty weight and payload capacity of wagon types are provided in Table 68.

Table 68: Empty weight and payload capacity of selected wagon types

Wagon type	Empty weight [tonnes]	Payload capacity [tonnes]	Vehicle capacity [TEU]	Max. total weight [tonnes]
Standard wagon *	23	61	-	84
Car wagon **	28	21 (10 cars)	-	49
Chemistry wagon **	24	55	-	79
Container wagon **	21	65	2,6	86
Coal and steel wagon **	26	65	-	91
Double container wagon*	25	100	4	125
Rolling Road –Truck wagon*	25.4	70	1	95.4
Rolling Road –Trailer wagon*	34.3	100	4	134.3
Building material wagon **	22	54	-	76
Manufactured product wagon **	23	54	-	77
Cereals wagon**	20	63	-	83

* Type specific values, used for general train type
**average values from transport statistics

Capacity utilisation of trains for different freight types

For railway transport, statistical data on the load factor is often not available. Railway companies usually report net tonne kilometres and gross tonne kilometres. Thus, the ratio between net tonne kilometres and gross tonne kilometres is the key figure for the capacity utilisation of trains. EcoTransIT World needs capacity utilisation as input. For energy and emission calculations, capacity utilisation is transformed to the net-gross-relation according to the following rules:

Abbr.	Definition	Unit
EW	Empty weight of wagon	[tonne]
CP	Payload capacity	[tonnes]
CU_{NC}	Capacity utilisation	[%]
CU_{NG}	Net-gross-relation.	[net tonnes/gross tonnes]

EcoTransIT World defines empty wagon weight and payload capacity of rail wagons for different wagon types (see Table 68).

The load factor for the “average cargo” of different railway companies is approximately 0.5 net tonnes per gross tonne [Railway companies 2002a]. For dedicated freight transports the value is between 0.3 and 0.66 net tonnes per gross tonne according to information from DB Schenker/ SNCF Geodis in 2012. According to [DB AG, 2008; Kienzler, H. P., 1998] the share of additional empty vehicle-km was 44% in 1996. This is due to a high share of bulk commodities in railway transport and a relatively large proportion of specialized rail cars. The share of additional empty trips for dedicated trains ranges from 20% to 100% (see Table 69). Thus, the share of empty vehicle-km in long distance transport is still significantly higher for rail compared to road transport.

The additional empty vehicle-km for railways can be partly attributed to characteristics of the transported goods. Therefore, we presume smaller differences for bulk and volume goods and make the following assumptions:

- The full load is achieved with bulk goods. Additional empty vehicle-km are estimated to be 80% for rail transport of bulk goods.
- The weight related load factor for average goods is estimated to be 60% for rail transport. In this case, the empty trip factor is estimated to be 50%.
- The weight related load factor for volume goods is estimated to be 30% for rail transport. In this case, the empty trip factor is estimated to be 20%.

For railway transport of dedicated cargo, average load factors and empty trip factors come from transport statistics of major railway companies (DB Schenker/ SNCF Geodis in 2012).

All assumptions and default average values used in EcoTransIT World are summarized in Table 69.

Table 69: Capacity utilisation of rail transport for different types of cargo

Cargo Type	Train wagon	Load factor LF_{NC}	Empty trip factor ETF	Capacity utilis. CU_{NC}	Relation Nt/Gt CU_{NG}
General Cargo	Bulk	100%	80%	56%	0.60
	Average	60%	50%	40%	0.52
	Volume	30%	20%	25%	0.40
Dedicated cargo	Car	85%	50%	57%	0,30
	Chemistry	100%	100%	50%	0,53
	Container	48%	20%	40%	0,55
	Double Container	48%	20%	40%	0,61
Rolling Road	Coal and steel	100%	100%	50%	0,56
	Building materials	100%	100%	50%	0,55
	Manufactured products	75%	60%	47%	0,52
	Cereals	100%	60%	60%	0,66

Source: ifeu estimations based on information from DB Cargo, SNCF Geodis

Capacity utilisation for container transport on rail

Rail transport uses the same container types as other transport modes. Different types as well as their empty weights are given in Table 3 in chapter 3.3.2. The gross weight of a container is the sum of net weight [t/TEU] and the container weight itself (see Table 3). The payload capacity [tonnes] of a container wagon is given in Table 69.

EcoTransIT World enables its users to define a value for t/TEU or t/FEU (freight mass per TEU or FEU) if a container transport is selected.

8.3 Rail freight GHG activities

8.3.1 Energy consumption (rail)

Energy consumption of electric trains

In EcoTransIT World, the final energy consumption of trains is calculated using functions, which are based on primary data from different EcoTransIT World member companies in Europe. In a survey, we collected data which covers almost 52 million train kilometres mainly in Germany, Austria and France based on information from DB AG, RailCargo and SNCF from 2019. These datasets included the gross tonne kilometres, train kilometres, energy consumption as well as further information on the different trains used.

Furthermore, the data was compared to the average energy consumption per locomotive type and gross tonnage from SBB in Switzerland.

All trains were grouped into weight classes (fine weight classes up to 2000 GTW with 10 tonnes increments and coarse weight classes for GTW >2000 with 100 tonnes increment) and their energy consumption was averaged using the train kilometres- thus data points with many train kilometres are weighted more than ones with very little train kilometres. Afterwards, the energy consumption per gross tonne kilometre (Gtkm) was plotted and fitted with a function. To achieve a better fitting, we use different functions for different weight classes.

The following functions are used in EcoTransIT World:

< 1000 GTW (power function):

$$EC_{spec}\left[\frac{Wh}{Gtkm}\right] = 369.46 \cdot GTW^{-0.457}$$

(EC_{spec}: specific Energy Consumption, GTW: Gross Tonne Weight)

≥ 1000 and < 2000 GTW (power function):

$$EC_{spec}\left[\frac{Wh}{Gtkm}\right] = 3137 \cdot GTW^{-0.767}$$

(EC_{spec}: specific Energy Consumption, GTW: Gross Tonne Weight)

≥ 2000 GTW (linear function):

$$EC_{spec}\left[\frac{Wh}{Gtkm}\right] = -0.0007 \cdot GTW + 10.577$$

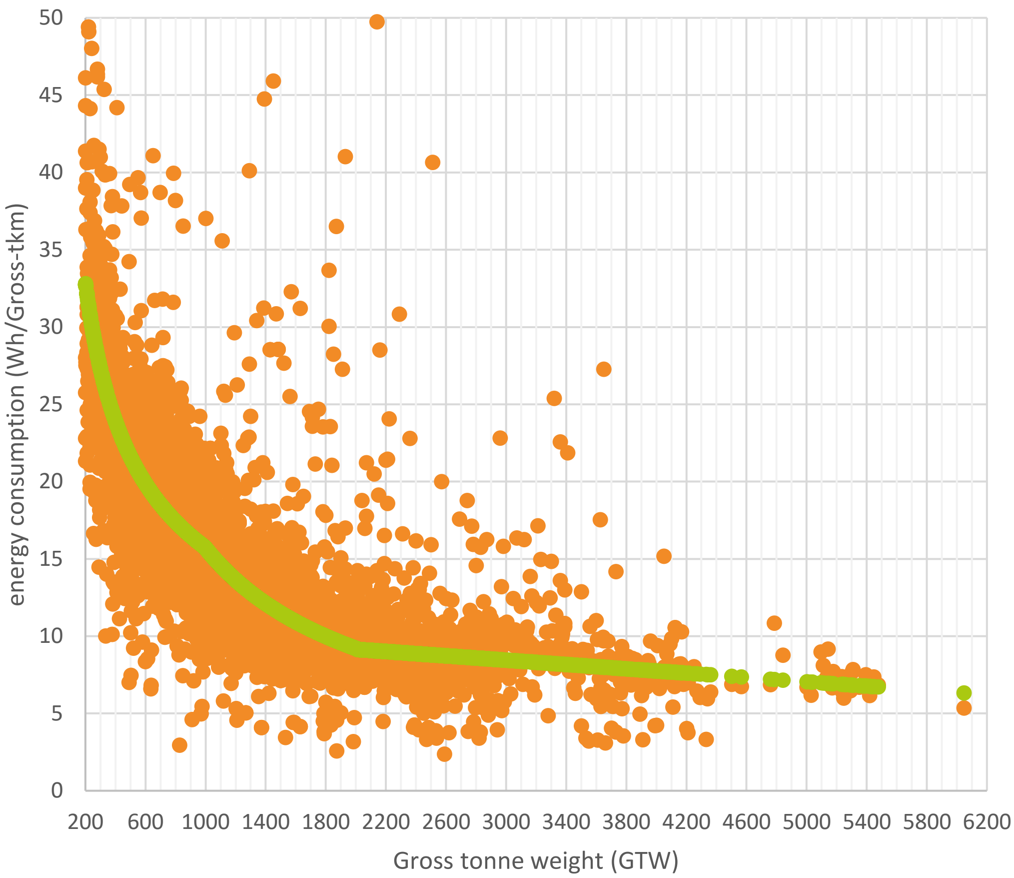
(EC_{spec}: specific Energy Consumption, GTW: Gross Tonne Weight)

The following diagram shows some of the actual values compared to new functions mentioned above.

The following conclusions can be stated:

- Many values lie close to the derived functions, however, there are outliers in all weight classes.
- Less datasets for very lightweight trains (below 200 GTW) or very heavy trains (above 4000 GWT) were submitted, thus for these trains the function(s) may be less valid.

Figure 19: Energy consumption of electric trains – actual data and functions



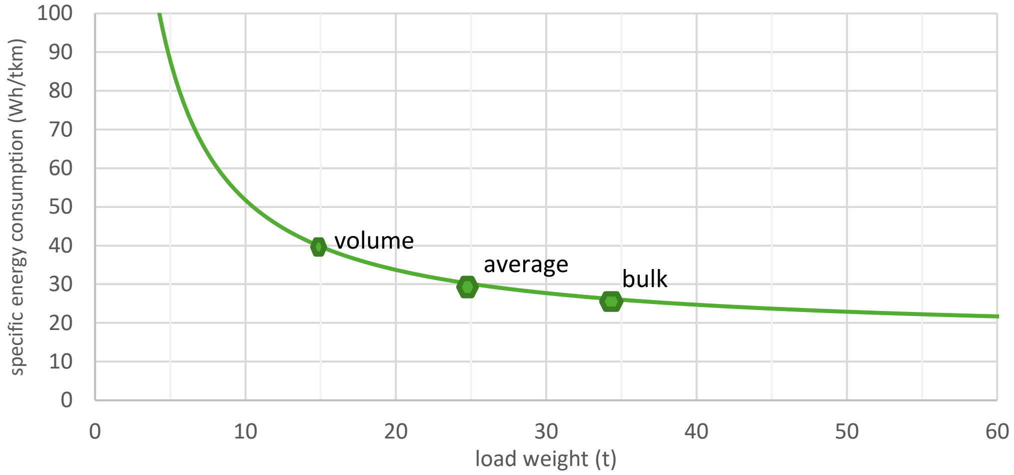
We do not differentiate between hilly, mountainous or flat countries, since we lack sufficient data to derive a suitable correction factor. Furthermore, SBB data proved that the energy consumption in Switzerland is in line with the data from other, less mountainous countries like Germany or France (which is due to more tunnels leading through the Alps like the new "Gotthard Basistunnel").

The specific energy consumption per net tonne km (Ntkm) is calculated for each train type with the following formula:

Specific energy consumption [Wh/Ntkm] =
Energy consumption of train [Wh/Gtkm] /
Relation Nt/Gt of freight (including empty trip factor)
Relation Nt/Gt = 0.40 for volume freight
0.52 for average freight
0.60 for bulk freight

The following chart shows the specific energy consumption in relation to the load weight for a 1000 tonnes electric train and the values for each freight type.

Figure 20: Specific energy consumption of an electric train of 1,000 Gt as function of load factor and values for each freight type



Remark: Load for volume/average/bulk goods including empty trips

The following table shows the specific energy consumption of the default electric trains for each freight type.

Table 70: Specific final energy consumption for selected electric trains

Train Type		Final Energy Consumption			
		Total	Freight		
		Train	Bulk	Average	Volume
General trains	Light Train (500t)	21.6	36.0	41.5	54.0
	Average Train (1000t)	15.7	26.1	30.2	39.2
	Large (1500t)	11.5	19.2	22.1	28.7
	Extra Large (2000t)	9.2	15.3	17.6	22.9
	Heavy (2500t)	8.8	14.7	17.0	22.1
Dedicated trains	Car	18.5		62.0	
	Chemistry	13.6		25.5	
	Container	15.7		28.3	
	Double Container	8.8		14.1	
	Rolling Road - Truck	13.6		27.6	
	Rolling Road - Semi Trailer	13.6		25.5	
	Rolling Road - Swap Body	13.6		27.9	
	Coal and steel	10.4		18.9	
	Building materials	13.6		24.7	
	Manufactured products	13.6		26.0	
	Cereals	12.8		19.3	

Including vehicle weight (container, truck, semi-trailer, swap body)

Source: ifeu assumptions based on data from DB Cargo, SNCF, RailCargo

Energy consumption of diesel trains

The available energy consumption data for diesel traction ranges between 2.6 and 9.7 g/gross tonne km according to internal statistics from several railway companies in 2002. Other statistics show a similar range [UIC, 2009]. The statistical uncertainties can be attributed to the unreliable assignment of the fuel consumption to different users (passenger and goods transport, shunting, etc.). Therefore, the primary energy consumption of diesel traction is estimated based on the primary energy consumption of electric traction. Thus, the same functional dependence as that of electric traction is taken and must be divided by the efficiency of the diesel-electric conversion for final energy consumption of 37%.

The following table shows the resulting specific energy consumption per Gtkm and Ntkm for different diesel trains and freight types. Some values for specific heavy trains from China and statistical averages for Canada and USA are added. The North American values are higher than values from the energy function. Thus, it is possible that North American railways have a higher energy consumption, but we propose to use the formula derived above also for North America, because the available North American database is very small.

Table 71: Specific final energy consumption for diesel trains

Train Type	Final Energy Consumption			
	Train Wh/Gtkm	Bulk	Freight Wh/Ntkm	Volume
			Average	
Light Train (500t)	58.3	97.2	112.2	145.8
Average Train (1000t)	42.4	70.7	81.5	106.0
Large (1500t)	31.1	51.8	59.7	77.7
Extra Large (2000t)	24.8	41.3	47.7	62.0
Heavy (2500t)	23.9	39.8	45.9	59.6
Values of heavy trains			Average (not specified)	
China 2008	27		-	
Canada 2003	33		61	
US Track 1 2006	-		66	
Light Train (500t)	58.3	97.2	112.2	145.8
Average Train (1000t)	42.4	70.7	81.5	106.0

Source: ifeu assumptions based on [EPS, 2005; USDOT, 2008]

Energy consumption of reefer containers on trains

For railway transport, the same 40-foot-high cube reefer containers as for truck transport are used. Their respective specifications, diesel consumption as well as air pollutant operational emissions are outlined in chapter 3.6.1.

The average speed for trains is set to 40 km/h (including breaks) and is used to convert the energy consumption per hour into energy consumption per tonne-kilometre.

8.3.2 Refrigerant losses (rail)

Reefer containers are usually transported in intermodal transports, thus, refrigerant losses for cooled train transports are handled like reefers on trucks. A description of how the refrigerant losses were derived can be found in chapter 3.6.2.

8.4 Air pollutant operational emissions (rail)

Emission factors for diesel train operation (TTW)

Similar to diesel engines for road and inland waterway transport, the emission performance of locomotive engines strongly depends on the engine technology. In the past years, the UIC, the EU and the US implemented emission limits for new engines in several stages, thus reducing specific emissions for newer engines. This fact is considered in EcoTransIT World by providing different emission factors per emission stage similar to road and inland waterway transport.

The following table lists the relevant emission stages and emission factors of the UIC, the European Union and the US-EPA.

Table 72: Emission standards for diesel trains (NO_x, NMHC, PM)

Region	Standard	Manufacturing year	HC	NO_x	PM
International: UIC (g/kWh)	UIC 1	<=2002	0,8	12	
	UIC 2	2003-2008	0,8	9,5	0,25
European Union, P>560 kW (g/kWh)	Stage IIIa	2009-2011	0,5	6,0	0,2
	Stage IIIb/V	>=2012	0,2	3,8	0,025
US-EPA, line-haul (g/bhp.hr)	Non-regulated	<1973	0,5	13,5	0,34
	Tier 0	1973-1992	1,0	8,0	0,22
	Tier 1	1993c-2004	0,6	7,4	0,22
	Tier 2	2005-2011	0,3	5,5	0,10
	Tier 3	2012-2014	0,3	5,5	0,10
	Tier 4	>2015	0,1	1,3	0,03

Source: [dieselnet.com, 2016]

Determination of emission factors for EcoTransIT World

For EcoTransIT World, these values can be transformed to fuel-related emission factors. Typical energy consumption values for locomotive engines are about 210 g/kWh [ifeu, 2003], therefore this value is used for the transformation.

For EcoTransIT World, a PM value for UIC 1 is added, based on engine data from engines with manufacturing year 1997 and before from [ifeu, 2003]. Table 73 shows the resulting emission factors used.

Table 73: Emission factors for diesel locomotives (freight transport) in EcoTransIT World

Region	Standard	Manufacture year	HC	NO_x	PM
International: UIC (g/kg)	UIC 1	<=2002	3,8	57,1	1,56
	UIC 2	2003-2008	3,8	45,2	1,19
European Union, >560 kW (g/kg)	Stage IIIa	2009-2011	2,4	28,6	0,95
	Stage IIIb/V	>=2012	1,0	18,1	0,12
US-EPA, line-haul (g/kg)	Non-regulated	<1973	4,1	73,8	1,53
	Tier 0	1973-1992	7,8	44,0	0,97
	Tier 1	1993c-2004	4,5	41,0	0,97
	Tier 2	2005-2011	2,2	30,2	0,48
	Tier 3	2012-2014	2,2	18,6	0,37
	Tier 4	>2015	0,5	4,8	0,11

Source: [dieselnet.com, 2016]; own assumptions

Country specific regulations and default values

The emissions values in Table 73 can be compared with existing data from railway companies (see Table 74). The comparison shows that the average cargo fleet of Deutsche Bahn (DB) in 2015 lies between UIC 2 and Stage IIIa. Other data could not be evaluated so far.

Table 74: Emission factors for diesel locomotives (freight transport) from different sources

Standard	Manufacture year	HC	NO_x	PM
DB 2016	All	2,6	42	0,96

Average values (g/kg), different sources

Due to the lack of a sophisticated survey, we propose a simple approach for default values in EcoTransIT World:

- For USA and Canada, the Tier 2 standard is used as default value
- For Germany the DB 2016 value is used
- For other EU 27 countries the emission factors of the UIC 2 standard are applied
- For all other countries the UIC 1 standard is assumed.

For future improvements we recommend asking UIC for country specific emission factors, which can be used as default values.

Option: particle filter

Several locomotives are equipped with a particle filter, which reduces PM-emissions considerably. For this reason, EcoTransIT World gives an additional option to choose a particle filter. As default a value of 0.012 g PM/kg is used in this case.

8.5 Shunting

In ETW shunting processes to collect and distribute freight wagons are not included in the calculation. Furthermore, the same is true for feeder trains, because private tracks from factory to the switch yard are not part of the routing in ETW.

Some railway companies have statistics about the operation performance and energy consumption for shunting. However, the effort can be very different for each transport process. Hence average values for a company are not suitable for a specific transport task.

The collection and distribution of wagons for single wagon trains is done on marshalling yards. A shunting locomotive, mainly with diesel traction, collects several groups of wagons and pushes them to a marshalling hump. Moved by the gradient, the wagons roll down to the tracks of the dedicated train, navigated by the control centre which chooses the track.

The energy consumption for shunting is calculated for a typical shunting cycle (MTU-shunting), which is described in [ifeu, 2003].

The following assumptions are made for a shunting process:

- Shunting locomotive, diesel, power 1000 kW
- Moving 15 wagons to the marshalling hump
- Total time of shunting process: 15 minutes (including empty runs of locomotive)
- Average motor load: 16% (MTU shunting standard)
- Average fuel consumption: 280 g/kWh (BR 290, [ifeu, 2003])
- Resulting total fuel consumption: 11.2 kg diesel / 15 wagons
  = 0.75 kg diesel / wagon = 32 MJ diesel / wagon

The total fuel consumption per wagon has to be allocated to the dedicated freight in one or several wagons.

9 Inland waterways transport (IWT)

9.1 IWT Transport Operation Categories (TOCs)

9.1.1 Overview

EcoTransIT World classifies inland waterway transports into transport operation categories (TOC) by the following parameters:

- Vessel type
- Waterway/river class: The waterways are classified by the CEMT scheme [CEMT, 1992][15]. By default, a representative vessel type is used for each CEMT class. Optionally, vessel types can be selected by the user, with the selection being limited to the waterways of CEMT classes each type can navigate.

9.1.2 Vessel types (IWT)

The inland waterway vessel types available in EcoTransIT World along with the capacity ranges they represent, and the CEMT classes they are used on by default or can be selected on, are listed in Table 75. The emission limit stage of inland barges can be selected. Please see Table 77 for available stages, and Chapter 9.4 for the default emission stage in inland waterway transport.

Table 75: Inland waterway vessel types with capacity ranges and CEMT classifications.

Representative vessel type	Capacity range	CEMT class in Standard mode/default	Selectable on CEMT class
Europa (or Euro) vessel	0 - 1500 t	I - IV	all
“Grossmotorschiff” (large inland freight vessel)	1500 - 3000 t	V	V - VII
JOWI class	>3000 t	VI	VI - VII
2x2 push convoy (Push boat and 2x2 “Europa” barges)	11'200 t (representative for convoys)	n/a	V - VII

15 Large navigable waterways are classified by the CEMT standard created by the European Conference of Ministers of Transport (Conférence Européenne des Ministres des Transports) in 1992. The standard specifies the maximum measures (length, bean, draught, tonnage) for ships to be able to navigate on rivers of each class.

The approach chosen for inland waterway transport differs from the one for ocean transport by using of representative/typical vessel types for each waterway class – while for ocean transport, aggregated vessel types are available by trade lane that represent a transport-performance-weighted average of all vessels that navigate on the respective trade lane. The former approach is more appropriate for inland waterway transport due to the lack of activity data on inland waterway navigation (especially outside Europe), which would add uncertainty to any tkm-weighted aggregation. For Europe, a comparison of mean fuel consumption factors with tkm-weighted aggregated classes shows that the three vessel types listed in Table 73 are representative of their size classes. World-wide, a comparison of EcoTransIT World emission factors with a report commissioned by the Global Logistics Emission Council (GLEC, [STC-Nestra, 2018]) has shown deviations ranging from –28% to about +38%, to the average CO_2 emission factors by vessel type cited from several studies for China, the U.S. and the Rhine basin. It should be noted that the assumptions on speed, cargo capacity utilization, or inclusion/exclusion of auxiliary engine fuel consumption in the sources cited by [STC-Nestra, 2018] are partially unknown, which may explain some of the differences.

9.1.3 Inland waterways in EcoTransIT World

Many waterways available in EcoTransIT World are located in Europe. All European waterways class IV and above are included in EcoTransIT World (Figure 21: European inland waterways available in EcoTransIT World and their CEMT classification.). Most prominent are the rivers Danube, Elbe, Rhine, and Seine[16], which are (at least in sections) classified as CEMT class VI. Other rivers and canals in Europe are classified as class V or smaller. The distinction between inland waterways up to class IV and above is important because the size and carrying capacity of inland barges significantly increases on class V and larger rivers.

16 There are other smaller sections that are technically “inland waterways” but are treated as part of the ocean network in EcoTransIT World. Those include the Weser up to Bremerhaven or the North-Baltic-Channel.

Figure 21: European inland waterways available in EcoTransIT World and their CEMT classification.

Worldwide, approximately 50 countries have navigable waterways of more than 1000 km length. Inland freight navigation is underdeveloped in many countries [BVB, 2009]. Besides Europe, mainly the USA and China demonstrate significant inland waterway transport performance [Amos et al., 2009]. EcoTransIT World enables inland waterways calculation on the largest global waterways, such as the Yangtze, Mississippi or Amazon rivers. The CEMT classification is not available for non-European waterways; therefore, the class V is assigned per default to all waterways outside Europe.

Figure 22: Worldwide inland waterways in EcoTransIT World.

9.2 Transport activity (IWT)

9.2.1 Distance calculation

The determination of an inland waterway route is based on the EcoTransIT World internal routing method (compare chapter 3.4.1). The inland waterway network consists of an attribute for the inland waterway class. Depending on the vessel size and the respective waterway class a waterway can be used or not within the routing.

Whereas the euro vessel can only be used on inland waterways above the class IV (standard European inland waterway), bigger barges need at least waterway class V or higher.

9.2.2 Transfer location identification

If no inland port is specified directly within the calculation request EcoTransIT World applies its transfer location identification where the freight can be transhipped to an inland vessel. The determination selects the closest nearby inland port from the origin or destination.

9.2.3 Freight types, payload, and utilization (IWT)

Both bulk and container transport can be selected on inland waterway vessels. The cargo capacities (maximum payloads) for bulk and containers, as well as the default capacity utilization (which can optionally be adjusted) are listed in Table 76.

Table 76: Cargo capacity, default capacity utilization, and further technical parameters of EcoTransIT World inland waterway vessel types.

Vessel type	Length [m]	Beam [m]	Installed power [kW]	Average speed [km/h]	Cargo capacity		Default capacity utilization	
					DWT (Bulk)	TEU (Container)	Bulk	Container
Europa vessel	85	9.5	737	10.5	1'350	100	60%	60%
Large inland freight vessel	110	11.4	1'178	10.5	2'500	200	50%	60%
JOWI class	135	17.34	2'097	10.5	5'300	450	50%	60%
2x2 push convoy	195	22.8	3'264	10.5	11'200	820	50%	60%

9.3 GHG activities (IWT)

9.3.1 Energy consumption (IWT)

As for sea transport, fuel consumption is modelled separately for main and auxiliary engine for a theoretical one-year period to account for emissions in port and return journeys and normalized to one tonne- or TEU-kilometre.

The energy consumption of the main engine is calculated as follows:

$$EC_M = \frac{P \cdot LF_{CU}}{V \cdot CU \cdot Cap} \cdot SFC \cdot \frac{EF}{1000}$$

With: EC_M = Energy consumption of the main engine [MJ/tkm or MJ/TEU-km]

P = Installed power [kW] [Panteia, 2013]

LF_{CU} = Load factor at default cargo utilization [ifeu and INFRAS, 2013]

V = Speed [km/h] [ifeu and INFRAS, 2013]

CU = Default cargo utilization [ifeu and INFRAS, 2013]

Cap = Capacity (dead weight tonnage or TEU) [Panteia, 2013]

SFC = Specific diesel consumption in g/kWh (200 g/kWh for all vessels based on [ifeu and INFRAS, 2013])

EF = Energy content of fuel in MJ/kg (see Table 14 for EU fuels/rest of the world and Table 21 for US fuels)

The input data related to the inland vessel fleet (nominal power, capacity) are sourced from [Panteia, 2013] and correspond to averages of the EU fleet. Load factors, cargo utilization is based on the German TREMOD model [ifeu and INFRAS, 2013]. The load factor at default cargo utilization is calculated from vessel type- and size class-specific load factors at full or empty load and for up- and downstream travel, respectively, that were derived for TREMOD from empirical data on energy consumption from German river sections [BMVBS, 2011; ifeu and INFRAS, 2013]:

$$LF_{CU} = LF_{empty} + \left(LF_{full} - LF_{empty}\right) \times CU$$

With: LF_{CU} = Load factor at default cargo utilization

LF_{empty} = Average load factor at empty load

LF_{full} = Average load factor at full load

The average load factors at empty/full load are calculated as the arithmetic average of the respective up- and downstream load factors. The fuel consumption of the auxiliary engine is assumed to be 5% of the consumption of the main engine, as in TREMOD [ifeu and INFRAS, 2013].Regarding fuel types, currently only diesel engines are considered for inland waterway transport. For some countries, biodiesel is blended in the Diesel used (see Chapter 4.3). Technical data on the inland barge types provided in EcoTransIT World are listed in Table 76.

9.3.2 Methane emissions (IWT)

So far, EcoTransIT World only includes diesel barges for inland navigation for which methane slip is not relevant.

9.3.3 Refrigerants (IWT)

Currently, EcoTransIT World does not provide cooled transports e. g. using reefer containers on inland vessels.

9.4 Operational air pollutant emissions (IWT)

Like diesel engines for road and rail transport, the emission performance of inland vessel engines strongly depends on the engine technology. In the past years the EU and US implemented emission limits for new engines in several stages, thus reducing specific emissions for newer engines. Table 77 lists the emission levels and emission factors available for EcoTransIT World. The factors for the emission stages "conventional", "CCNR I" and "CCNR II" were derived from type approval data and literature data for European vessels, see [ifeu and INFRAS, 2013]. Emission factors for EU V are based on an analysis by [Ligterink et al., 2019]. The emission limits for the EU V stage vary depending on the engine power class. For simplification EcoTransIT World assumes a ratio of 35% of vessels with engines <300 kW and 65% >300 kW, based on data for Germany in the TREMOD model [Allekotte et al., 2024]. For the US Tier 3 and US Tier 4 emission factors, type-approval data from the US EPA for marine engines of model years 2000-2022 were derived for engines of categories 1 and 2 [EPA, 2021].

Since inland vessels typically have lower engine loads in real-world operation than in type approval testing, all emission factors imply in-use correction factors for an average engine load factor of 35% (see [Ligterink et al., 2019]). This leads to higher emission factors than for the emission limit value, especially for newer engines.

Table 77: Inland vessel engine emission factors in gram per kWh (engine power).

Emission stage (manufacture year)	NO_x (g/kWh)	NMHC (g/kWh)	PM (g/kWh)
conventional (1970-2002) / US Tier 1	11,89	0,70	0,42
CCNR I (2002-2007)	9,27	0,50	0,13
CCNR II/ EU IIIA / US Tier 2 (2008-2021)	7,77	0,37	0,13
EU V (2022+) weighted (35% <300kW, 65%>=300 kW)	3,01	0,28	0,05
US Tier 3	5,44	0,24	0,14
US Tier 4	2,31	0,06	0,03

Sources: [ifeu and INFRAS, 2013], [Ligterink et al., 2019], [EPA, 2021], ifeu assumptions.

Inland vessel engines typically have a long service life, which means that some of the vessels still use unregulated engines. The default setting in the EcoTransIT World calculator for the emission level of inland vessels is "CCNR I (2002-2007)", based on the average fleet composition and emission factors in Germany in 2020 [Allekotte et al., 2024]. No data was available on whether this is representative for other countries. However, expert users can calculate emissions with more recent emission levels if they have detailed knowledge of the vessel or engine age.

10 Logistics hubs

Logistic hubs play a connecting role within transport chains and refer to all sites where freight is handled from one vehicle or transport mode to another or are the starting or end point of transport chains. The assessment scope follows the requirement of ISO 14083 and the methodology as described in more detail in [Dobers and Jarmer, 2025]

The EcoTransIT World provides the possibility to assess the environmental impact of logistics hubs' operations, based on company's actual data. If actual data is not available, EcoTransIT World uses default values for the transshipment of goods. The background of these default values is described in section 10.3.3.

10.1 Hub operation categories (HOCs)

EcoTransIT World covers transshipment by common types of transfer points within one mode or between modes, and related freight types as listed below.

Table 78: Transshipment at transfer points

Name	Transport mode(s)	Freight types*
Cross-docking	Road	Average
Rail-road terminal	Rail, road	Containerized/swap bodies, trailers
Terminal at sea or inland port	Sea, inland water, rail, road	Containerized/swap bodies, piece goods/break bulk, liquid bulk, dry bulk
RoRo terminal	Sea, rail, road	Vehicle transport
Terminal at airport	Air, road	Average

* Average, ambient, temperature controlled (cooled, frozen, heated)

In general, only transshipment of freight is considered. When using company's primary data, the storage of goods may be covered as an option.

10.2 Hub activity

The default hub activity is "tonnes throughput" as required by ISO 14083. Alternatively, the hub activity may be e.g. TEU, FEU, or boxes in container terminals or vehicles in RoRo terminals. For default values refer to Table 81.

Remark: As "throughput" may differ from one to another company, e.g.,

- whether inbound plus outbound or only outbound, or
- in case of intermodal terminals: whether all goods from all modes

are covered, its definition as set by ISO 14083 is again highlighted here: The hub activity is the throughput *outbound* and refers to *all goods of all modes* handled at the specific site.

10.3 Hub GHG activities

Logistics hub operation causing greenhouse gas emissions include following activities: (for further details see also [Dobers and Jarmer, 2025, p. 19ff.])

- Transport and handling of goods by dedicated on-site vehicles and equipment: e.g., equipment for yard logistics, shunting, tugboats, ground support (GSE), apron and/or ramp services resp. ramp handling as well as material handling equipment (MHE)
- Operation of buildings or other infrastructural services on-site needed for operating the location: e.g., lighting, heating and air-conditioning, temperature control of goods (e.g., reefer station)
- Operation of vehicles/vessels or equipment that transport employees who steer self-driving vehicles in a roll on/roll off terminal
- Energy life cycle as outlined in section 3.1.2

Excluded activities are:

- Inbound and outbound vehicles/vessels as these activities are covered by transport (see chapters 3.7 to 0)
- Vehicles used to transport crew members within terminals
- Other excluded processes as specified in section 3.1.2

10.3.1 Energy demand (hub)

EcoTransIT World considers the following energy carriers for logistics hubs:

- Material handling and other equipment (excluding heating): Electricity, diesel, petrol, LNG, CNG, LPG, hydrogen, propane
- Heating: Natural gas for heating, heating oil, steam, district heating, geothermal energy, wood chips, wood pellets, diesel or biodiesel

The consideration of energy consumption at logistics hubs is realized by using hub-specific consumption factors for each energy carrier per unit throughput outbound (e.g., MJ electricity/tonne). The consumption factors may be either individual factors based on primary data or default values as described below.

10.3.2 Refrigerant losses (hub)

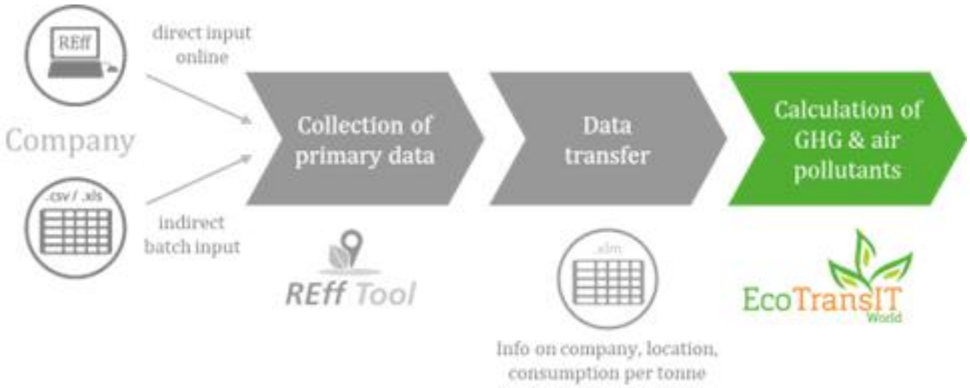
EcoTransIT World considers the refrigerant types for logistics hubs as outlined in Table 80. The consideration of refrigerant leakage at logistics hubs is realized by using hub-specific refill factors for each refrigerant type per unit throughput outbound (e.g., kg R-410A/tonne). The refill factors may be either individual factors based on primary data or default values as described below.

10.3.3 Primary data collection for user specific HOCs

Process flow for collection of real data

Data collection at company's level is realized using the REff Tool® (https://reff.iml.fraunhofer.de/). Here, data entry can either be performed manually (direct input online) or indirectly (e.g., supported batch import by Fraunhofer IML). The data is transferred from the REff Tool® to EcoTransIT World by an XML-script as shown in the following figure.

Figure 23: Process flow for collection of real data



Data collection

- **Data on location of hub:** The logistic hub is located in the EcoTransIT World network using its name, street, street number, zip code, city and country.
- **Balance year:** The company's primary data (consumption data and logistics data) must refer to a 12-month reporting period.
- **Consumption data:** In EcoTransIT World, the calculation of emissions refers to energy consumed and leakage of refrigerants that need to be refilled within the balance year (this does not refer to the initial filling of cooling equipment). The following consumption data can be specified:

Table 79: Collection of annual data on fuel types at logistics hubs

Name	Transport mode(s)		
Electricity	Compressed natural gas CNG	Natural gas or biogas	Heating oil
Diesel, biodiesel or blend	Liquefied petroleum gas LPG	District heating	Wood chips
Petrol, ethanol or blend	Liquefied natural gas LNG	Geothermal energy	Wood pellets
Hydrogen	Propane	Diesel, biodiesel or blend	Steam

Table 80: Collection of annual data on refrigerant types at logistics hubs

Leakage or refill of refrigerants				
R-12	R-143a	R-407F	R-448a	R-513A
R-22	R-152a	R-408A	R-449A	R-600
R-23	R-218	R-409A	R-450A	R-600a
R-32	R-290	R-410A	R-452a	R-717
R-115	R-401A	R-413A	R-502	R-744
R-124	R-402A	R-417A	R-504	R-1234ze(E)
R-125	R-404A	R-417C	R-507	R-1234yf
R-134a	R-407A	R-422A	R-507A	ISCEON 89
R-142b	R-407C	R-422D	R-509A	FX 100 (R-427A)

Logistics data: As outlined above, the calculation of hub emissions refers to the annual throughput outbound of the logistic hub, for example the number of outbound shipments. The base unit is tonnes. However, the company may also choose other base units such as pallet, parcel, shipment, piece good, TEU, box, vehicle. If an alternative base unit is chosen, an individual conversion factor [tonnes/base unit] needs to be specified.

Data transfer: The REff Tool® elaborates the required transfer script (XML) covering the following information per hub:

(1) Inventory including name and start/end date (always referring to one year);

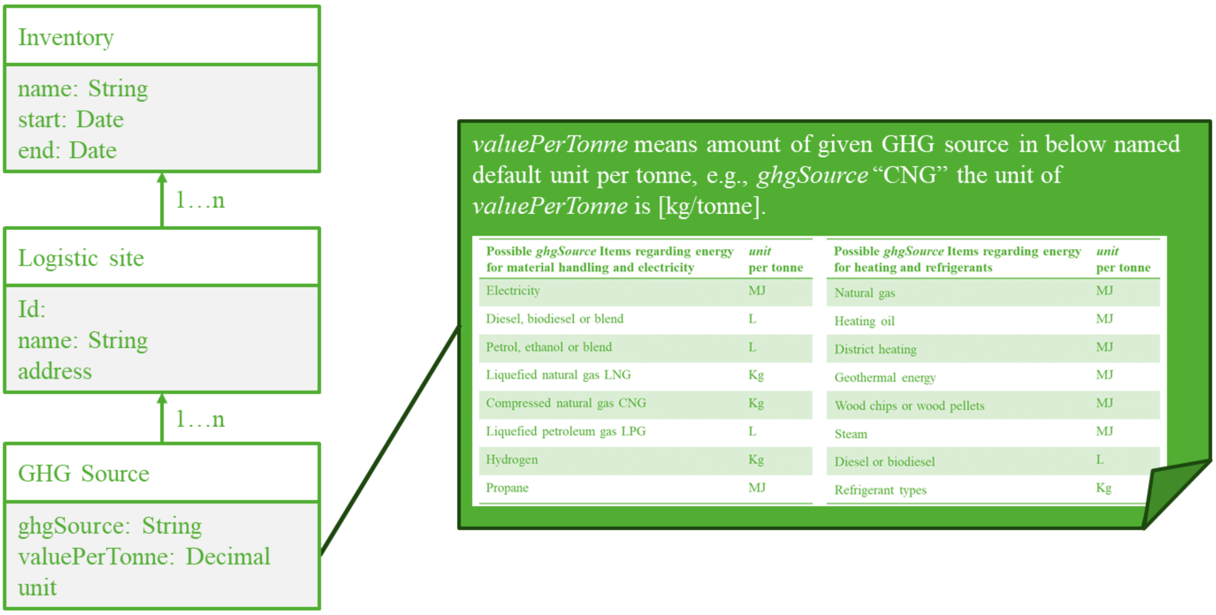
(2) Logistics hub including REff Tool® specific ID of hub, name and address;

(3) GHG sources and their relevant intensity i.e., quantity per tonne.

The REff Tool® also provides a second export file (csv), that lists all already defined hubs including hub IDs to enable a quick overview as well as the possibility to individually share hub information within a network of companies using EcoTransIT World.

Hub ID: The REff Tool® automatically assigned each hub with an individual ID which is included in the transfer script (XML). This ID is unique within the REff Tool® and remains unchanged over time.

Figure 24: Transfer script for logistics hub



Emissions calculation: When considering user specific logistics hubs' operations in EcoTransIT World, the relevant hubs need to be first imported into the REff Tool® as described above. The relevant hubs (*ID*) are identified for the selected transport chains and the provided hub-specific emission sources and consumption parameters (either default or individual values) [emission source/tonne] multiplied by the amount of freight transshipments.

Default values for logistics hubs

Basing on annual market surveys (since 2021) on logistic hubs offering transshipment and storage, conducted by Fraunhofer IML and partners (https://reff.iml.fraunhofer.de/), an initial set of default consumption values for logistics hub IDs has been implemented in EcoTransIT World. These activities have been accompanied in 2025 by a dedicated study on intermodal terminals, performed by SGKV and Fraunhofer IML, supported by EcoTransIT World.

The defined mapping of logistic hub ID and application field considers inbound transport mode (road, rail, sea, air, inland waterway), freight type (dry, container, liquid, pallet, piece, RoRo) and temperature level (ambient, cooled).

In total, 944 hubs - covering warehouses, transshipment hubs, container and liquid bulk terminals - of 184 companies have been analysed to determine the default values in Table 81. Depending on the data quality for the respective hub type the underlying sample size might be lower as indicated.

For container terminals, no detailed information is currently available that allows a differentiation of handling of ambient/dry and temperature-controlled goods such as by allocating (partial) resource consumption to the good types. Therefore, a more generic approach has been applied: The average values of all terminals handling dry as well as temperature-controlled goods (total count: 13 terminals) were used for ambient goods handling. This is a small overestimation of emissions for ambient goods (conservative approach) which is acceptable for default values. For elaborating intensity values for temperature-controlled goods, research conducted by Universidad de los Andes [Dobers et al., 2023] was applied: According to the researchers, refrigerated containers cause 17% more emissions than ambient containers (12.57 kg CO_2e/container vs. 10.70 kg CO_2e/container). Therefore, a surcharge value of 17% was applied for electricity consumption.

Table 81: Default values for logistics hubs

ID	Logistics hub type	Sample size	Electricity [kWh/t]	Natural gas (heating) [kWh/t]	Diesel [L/t]	R-404A [g/t]
1	Transshipment, ambient, default	270	3.85	1.41	0.12	0.51
2	Transshipment, mixed, default	51	4.93	1.47	0.08	1.50
3	Container terminal, dry, default	13	0.83	0.05	0.23	-
4	Container terminal, cooled, default	-	1.37	0.05	0.23	-
5	Bulk terminal, mixed, default	55	6.69	5.87	0.04	-

Automatic transshipment detection

EcoTransIT World can automatically detect and include energy consumption, leakage of refrigerants and emissions associated to any transshipment activities, based on the logistics hub data. The user can choose to include these emissions for all transshipment activities -each time a new leg is created-or only for intermodal transshipments, when the transport mode changes. On top of that the user must specify the handling type (dry, container, liquid, pallet, piece, RoRo) and whether the transport is refrigerated, so that the appropriate default values are applied.

10.4 Emission factors (air pollutants, GHG)

Logistics hubs typically use multiple energy carriers and refrigerant types. EcoTransIT World supports the use of the energy carriers and refrigerants as listed in Table 79 and Table 80. The relevant emission factors or possible sources for each energy item are provided in chapter 4.

10.4.1 Emission factors for refrigerants

Table 82 summarizes emissions factors for refrigerants covered by EcoTransIT World. The ISO 14083 recommends using Global Warming Potential) GWP values from the latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report, which, at the time of this report's publication, is the 6th Assessment Report [Smith et al., 2021]. In case of refrigerant blends, the GWP values have been calculated based on the indicated shares.

Table 82: GHG emission factors of refrigerant types[Dobers and Jarmer, 2025]

Refrigerant type	Description	IPCC 2021, AR6 [g CO_2e/g]
R-12	CF2Cl2 // CCl2F2, Dichlordifluormethane	12,500.0
R-22	CHClF2, Chlorodifluoromethane	1,960.0
R-23	CHF3, Fluoroform	14,600.0
R-32	CH2F2, Difluoromethane	771.0
R-115	CClF2CF3, Chloropentafluoroethane	9,600.0
R-124	C2HF4Cl // CHClFCF3, 1-Chlor-1,2,2,2-tetrafluorethan	597.0
R-125	CHF2CF3, Pentafluoroethane	3,740.0
R-134a	CH2FCF3, 1,1,1,2-Tetrafluorethan	1,530.0
R-142b	C2H3F2Cl, 1-Chlor-1,1-difluorethan	2,300.0
R-143a	CH3CF3, 1,1,1-Trifluorethan	5,810.0
R-152a	C2H4F2 // CH3CHF2, 1,1-Difluorethan	164.0
R-218	C3F8, Octafluorpropane	9,290.0
R-290	C3H8, Propane	0.02
R-401A	Mixture, own calculation: 53% R-22, 13% R-152A, 34% R-124	1,263.1
R-402A	Mixture, own calculation: 60% R-125, 2% R-290, 38% R-22	2,988.8
R-404A	Mixture, own calculation: 44% R-125, 4% R-134a, 52% R-143a	4,728.0
R-407A	Mixture, own calculation: 20% R-32, 40% R-125, 40% R-134a	2,262.2
R-407C	Mixture, own calculation: 23% R-32, 25% R-125, 52% R-134a	1,907.9
R-407F	Mixture, own calculation: 30% R-32, 30% R-125, 40% R-134a	1,965.3
R-408A	Mixture, own calculation: 7% R-125, 46% R-143a, 47% R-22	3,855.6
R-409A	Mixture, own calculation: 60% R-22, 25% R-124, 15% R-142b	1,670.3
R-410A	Mixture, own calculation: 50% R-32, 50% R-125	2,255.5
R-413A	Mixture, own calculation: 88% R-134a, 9% R-218, 3% R-600a	2,182.5
R-417A	Mixture, own calculation: 46,6% R-125, 50% R-134a, 3,4% R-600	2,507.8
R-417C	Mixture, own calculation: 19,5% R-125, 78,8% R-134a, 1,7% R-600	1,934.9
R-422A	Mixture, own calculation: 85,1% R-125, 11,5% R-134A, 3,4% R-600a	3,358.7
R-422D	Mixture, own calculation: 65,1% R-125, 31,5% R-134a, 3,4% R-600a	2,916.7
R-448a	Mixture, own calculation: 26% R-32, 26% R-125, 20% R-1234yf, 21% R-134a, 7% R-1234ze(E)	1,494.4
R-449A	Mixture, own calculation: 25,7% R-134a, 25,3% R-1234yf, 24,7% R-125, 24,3% R-32	1,504.5
R-450A	Mixture, own calculation: 42% R-134a, 58% R-1234ze(E)	643.4
R-452a	Mixture, own calculation: 11% R-32, 59% R-125, 30% R-1234yf	2,291.6
R-502	Mixture, own calculation: 48,8% R-22, 51,2% R-115	5,871.7
R-504	Mixture, own calculation: 48,2% R-32, 51,8% R-115	5,344.4
R-507	Mixture, own calculation: 50% R-125, 50% R-143a	4,775.0

R-507A	Mixture, own calculation: 50% R-125, 50% R-143a	4,775.0
R-509A	Mixture, own calculation: 44% R-22, 56% R-218	6,064.8
R-513A	Mixture, own calculation: 44% R-134a, 56% R-1234yf	673.5
R-600	C4H10, n-Butane	0.006
R-600a	C4H10, Isobutane	0.006
R-717	NH3, Ammonia	0
R-744	CO_2, Carbon dioxide, dry ice	1.0
R-1234ze(E)	C3H2F4 // trans-CF3CH=CHF, (E)-1,3,3,3, -Tetrafluorpropene	1.4
R-1234yf	C3H2F4 // CF3CF=CH2, 2,3,3,3-Tetrafluorpropen	0.5
ISCEON 89	Mixture, own calculation: 86% R-125, 9% R-218, 5% R-290	4,052.5
FX 100 (R-427A)	Mixture, own calculation: 50% R-134a, 25% R-125, 15% R-32, 10% R-143a	2,396.7

Source: [Dobers and Jarmer, 2025]

11 Reporting

Reporting is a fundamental part of any calculation of greenhouse gas emissions in accordance with ISO 14083, which is why ISO 14083 contains requirements for the reporting framework and specifies what information must be reported. In accordance with ISO 14083 the report can be created from two different perspectives: At the level of transport or hub activities or at the level of the organization. In the context of emission reporting on organizational level, the following scopes according to the GHG protocol can be differentiated: Scope 1 emissions correspond to emissions caused by the vehicles and logistics hubs operated by the company, whereas Scope 2 and 3 refer to indirect emissions generated in the course of upstream and downstream activities. For example, GHG emissions from the operation of a vehicle are also referred to as TTW emissions and can be assigned to Scope 1 or Scope 3 emissions under the GHG Protocol. Depending on who is responsible for the operation and who wishes to report the GHG emissions, they can be assigned to Scope 1 or Scope 3 emissions according to the GHG Protocol. Regardless of the scope in which the emissions are caused, ISO 14083 requires a differentiation between emissions arising from operations and emissions arising from energy provision. Compliance with ISO 14083 requires a report on GHG emission results. This enables the consistent and transparent information exchange along transport chains between partners and organizations as well as their possible reuse in other calculations as indicated in the previous section. Currently, EcoTransIT World users are responsible to issue their own ISO 14083-compliant reports, however, all information needed to write such a report is included in this methodology report which can also be referenced for this purpose.

In the future, we plan to provide more guidance to help drafting such a report, this might include a template for EcoTransIT World users to start from.

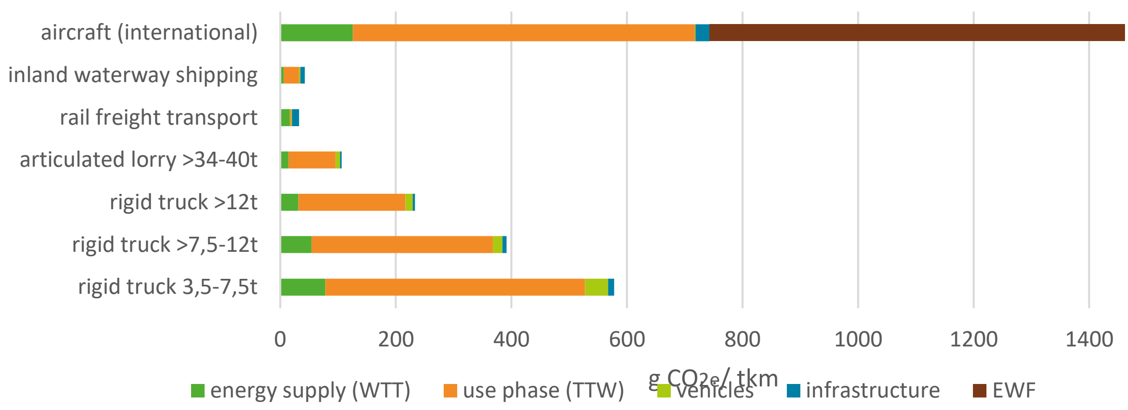
12 Context of life cycle assessment (LCA)

The ISO 14083 does not include the transport infrastructure (streets, railways…) and the vehicles used for transport (e. g. manufacturing, maintenance and end-of-life for trucks, airplanes, trains and vessels). In this chapter a short information on the relevance for these processes for the entire process chain is given.

A study for the Umweltbundesamt (ifeu/Infras/Öko-Institut 2020) shows that the relevance of the vehicle and the infrastructure differs for the various transport modes, vehicle sizes and environmental impact categories.

In general, greenhouse gas emissions today as well as emissions of air pollutants are dominated by the well-to-wheels (WTW) emissions. For the GHG emissions, the infrastructure contributes only marginally to the overall impacts. Vehicles are also almost irrelevant for air, train or vessel and have a very low impact for trucks. The nitrous oxide emissions show a slightly bigger, but still very small, contribution from infrastructure and vehicles to the overall process chain.

Figure 25: Comparison of the GHG emissions from road transportation in Germany in 2017 in g per tkm



Source: [ifeu/ infras/Öko Institut 2020]

*Vehicles include production, maintenance and end-of-life

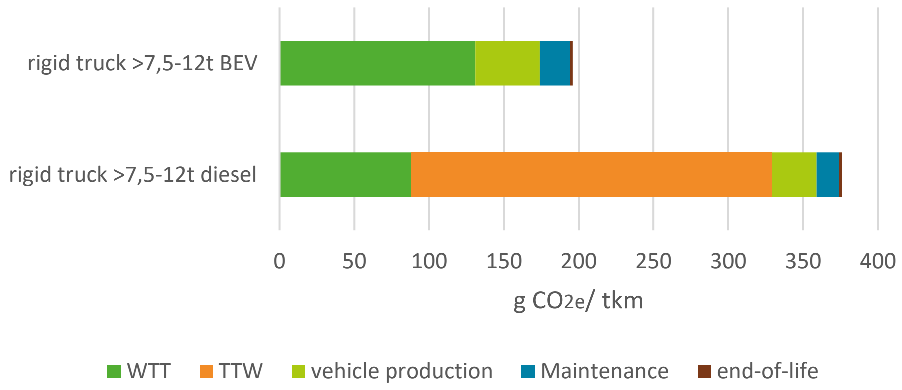
** For aircraft, the additional climate impacts of emissions at high altitudes are included by using an emission weighting factor (EWF). More details on these effects can be found in chapter 6.6.1.

More relevant are the contributions from the particulate emissions. In recent years, direct particulate emissions at the vehicle exhaust level have decreased greatly, leading to a higher contribution of the WTT part of the process chain and the emissions from vehicles and infrastructure. Today, most vehicles run on fossil fuels. In the future this picture may however be changing. The introduction of electric vehicles leads to an increase of the emissions from vehicle manufacturing due to the high impacts from the lithium-ion battery. Electric trucks have no operational greenhouse gas or air pollutant emissions, but the provision of the electricity today leads to still considerable impacts in most countries worldwide.

These impacts will likely decrease in the future when more renewable energy is used for electricity generation.

A study done by Ricardo, ifeu and e4tech for the European Commission [Hill et al., 2020] concludes that the battery manufacturing of lithium-ion batteries today leads to greenhouse gas emissions of around 80 kg CO_2e per kWh battery capacity. Even though the emissions from the vehicle provision increase compared to the conventional truck, when using an average European electricity mix, a battery electric truck with 12 t gross vehicle weight (GVW) has almost half the GHG emissions compared to a diesel truck.

Figure 26: Comparison of the GHG emissions for a 12 t GVW truck in 2020 with EU electricity mix



Source: [Hill et al., 2020]

This assessment shows that even though the emissions from vehicle manufacturing are increasing for alternatively fuelled vehicles, GHG emissions are still dominated by the operational (WTW) part of the process chain.

13 Appendix

13.1 Detailed description of the refinery model

Crude oil supply

The crude oil supply data for all fossil fuels are based on information compiled by ESU 2021 for Europe [Bussa, M. et al., 2021; Meili, C. et al., 2021]. These include current data on energy consumption and on import routes and account for the increased methane emissions.

Refinery

The ifeu refinery model [ifeu, 2021] has been developed at the end of the nineties of the last century, when consistent life cycle inventory data for refinery products became essential for the quality of LCA comparisons of diverse mineral oil products. The model has been updated and expanded periodically. Today, it represents the current European state-of-the-art. The basic setting of the model reflects the technical characteristics of European refineries as described in the BREF - BAT reference document for the Refining of Mineral Oil and Gas [Barthe, P. et al., 2015]. Further specific data was collected from companies and production plants and was incorporated to elaborate a comprehensive and robust model of a refinery.

The ifeu refinery is modelled in the LCA software Umberto and represents the complexity of petroleum refinery plants in which the combination and sequence of processes are usually very specific to the characteristics of the raw materials (i.e. the close relation between the composition of the crude oil and the products to be produced). Refineries differ not only in their configurations, process integration, feedstocks, product mixes, unit sizes, designs, and control systems, but also the market situations, locations and individual refinery ages as well as environmental regulations can result in a wide variety of refinery concepts. These specifications define the requirements for the ifeu model.

Figure 27: Screenshot of the ifeu petroleum refinery model in UMBERTO

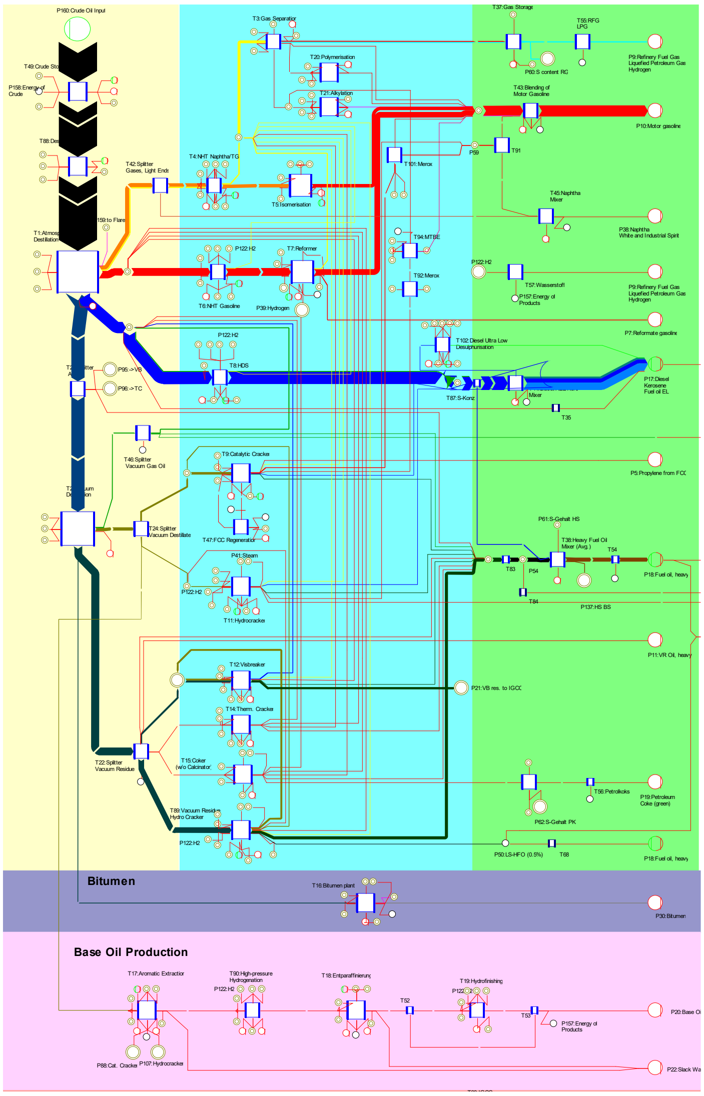


Figure 27 gives a schematic overview of part of the model network, showing how the structure of the model integrates all processes and configurations as given by the refineries in Europe, representing a technical integral over the European situation. The "default" setting (mass flows, products and product ranges, energy requirements and efficiencies, emission levels) is adjusted to the European weighted average, derived from the BREF (BREF section 1.3.3) and Eurostat-data, considering the changed product mix in recent years. The weighted average is determined by the actual overall capacities of the process types.

The BREF contains not only aggregated numbers or weighted averages of emission and energy or water consumptions but also encompasses primary data of the majority of refineries in Europe in anonymous form. The data quality is excellent. This data source has been complemented by various specific confidential refinery datasets, by values from Eurostat (e.g. in the case of the energy source mix or process energy), and by literature data from widely acknowledged sources such as [Meyers, 2003] and others. In the case of the BREF, a range of values were mentioned as process parameters for which the arithmetic averages were applied. After adapting the model to the up-to-date mass and energy flows within the European refineries, it has been validated and calibrated by comparing the results to the dataset of the BREF as well as the Eurostat and the European Pollutant Release and Transfer Register [E-PRTR, 2019].

Allocation procedures within the refinery model

Mineral oil refineries are highly integrated and multi-output production plants. For example, a waxy distillate – basic feedstock for base oils – cannot be produced without producing petrol, diesel or fuel oil and vice versa. Nearly each process step creates a few co-products. Therefore, a clear and consistent way for the calculation of the total input (consumptions) and the total output (emissions) per product has to be carried out.

Unlike many other refinery models which tend to consider a refinery as a black-box, the ifeu refinery model calculates step by step the complex network of refinery processes (atmospheric distillation, vacuum distillation, visbreaker, hydrocracker, etc.), and gives an integrated sum of all connected modules. The allocation is executed within each of these steps allowing the implementation of the allocation rules at process step level separately and globally, over the system of all steps. The environmental "backpack" of each final product is allocated automatically by the LCI functionality given in Umberto.

The allocation approach implemented within the ifeu refinery model is designed to consider:

a. the complexity of the production system.

b. the valuation of the products (upgrading/downgrading of feedstock material during a specific process);

c. real physical mass flows.

The combination procedure described below follows the logical consequence of the pre-settings described above, driven by "common sense" and is in line with the ISO 14044 guidelines on life cycle assessment.

The combined allocation procedure is stated by the following sequence of four rules:

1. In general, allocation is weighted according to the products' energy content, i.e. their lower heating values

   Rationale: Most refinery products are used for energy purposes.

2. The burdens for the first step of separation (atmospheric distillation) are allocated to all co-products, including the atmospheric residue (bottom product)

Rationale: All co-products from atmospheric distillation will end up in marketable final products.

3. The burdens for any subsequent process step that is intended to reduce the quantity of non-intended products (i.e. vacuum distillation and cracking) are allocated to all co-products except for the unintended bottom products (e.g. vacuum residue, cracking residue; see box below with definition of the term "residue" – note that Liquid Petroleum Gas (LPG) may also be considered as an non-intended product, therefore "non-intended" is also defined there).

   Rationale: All these downstream processes within the refinery are designed to reduce unintended products in order to increase the yield of the main intended co-products; hence, the burdens are only allocated to the yielded products.

4. Retention of feedstock: The 3rd rule refers to the allocation of the respective process burdens; it does not include the allocation of feedstocks. The input material (feedstock) into a refinery process step is always allocated according to the 1st rule: e.g. visbreaker residue takes 40% of the totalized co-product output of a visbreaker cracker, thus 40% of the visbreaker input (vacuum distillate) and its upstream burden is allocated to the visbreaker residue

   Rationale: Although the downstream processing steps (cracking) are not intended to produce bottom products only to reduce them, the remaining bottom products derived from these processes (e.g. heavy fuel oil, petroleum coke) are defined as refinery products and not as wastes; if the 3rd rule would also apply for the allocation of feedstock, all final products from bottom products would finally achieve LCIs with zero burdens and emission; de facto they would be treated the same way as waste.

The combined allocation procedure results in the following consequences:

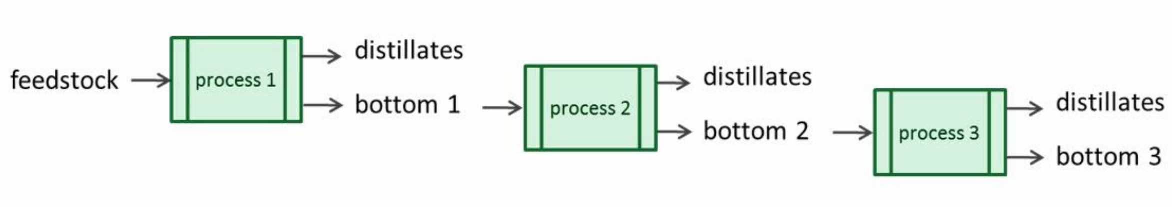
- The LCI (Life Cycle Inventory) of every refinery product encloses at least 1 MJ crude oil per MJ product feedstock; considering that some refinery products have lower heating values than crude oil (e.g. petroleum coke or heavy fuel oil), such refinery products enclose less than 1 kg crude oil per kg product.
- Final products with relevant shares derived from sequential processing accumulate higher "back packs" than products predominantly derived from straight run.
- An exception is the heavy products derived from bottom products, even if they pass a cascade of cracking processes; without rules 3 and 4, heavy fuel oil would turn out to be the product with the highest backpack, which would contradict any value-based perception of the refining business.

Definition of the term "residue" in this context:

There are diverse definitions and conceptions of the item "residue". In the context of the refinery allocation procedure, the item is strictly bound to two conditions:

1) Technical parlance: residue as an explicitly defined output of a fractionation step (bottom product of a distillation, also after cracking), known as atmospheric residue, vacuum residue, visbreaker residue etc.)
2) Material flow thinking residue as a non-intended output of process, but not meeting the criterion for "waste status"

In consequence, residues are always considered as co-products, never as waste – despite certain "waste attributes". The applied combined allocation procedure adopts the ISO's consideration of "partly co-products and partly waste" in this way:



- Bottom 1 is one of the co-products from process 1 and therefore treated like all co-products (distillates and bottom) from process 1.
- Bottoms 2 and 3 are non-intended outputs from processes 2 and 3, respectively, because these processes are intended to reduce the occurrence of residuals. Consequently, they don't carry any burdens from process 2 and process 3, respectively. The "co-product part" relates to the attribution of feedstock and expenditures/emissions from process 1, while the "waste part" is reflected by neglecting expenditures/emissions from process 2 and 3.

Definition of the term "non-intended" in this context:

Apart from bottom products generated from upstream bottoms, there might be need for a generic definition of "non-intended" outputs. Even some distillates might be questioned to be fully intended, e.g. Liquid Petroleum Gas (LPG).

A helpful baseline for a definition can be taken from the European Waste Directive, defining "by-products" as "*substance or object, resulting from a production process, the primary aim of which is not the production of that item*" which are ready for certain, non-conditioned and lawful use (Art. 5, 2008/98/EC). However, refinery outputs are complex to be judged. Considering the complexity of their configuration and multitude of co-products, it is challenging to define *primary aims* of running a refinery.

We therefore provide a stepwise approach for the distinction between intended and non-intended:

Step 1: final products with market prices higher than crude oil are considered to be intended.

Step 2: final products with market prices lower than crude oil but which supply basic products for markets which cannot be served easily by alternative products (e.g. bitumen, for a comprehensive list, see Appendix B) are intended.

Step 3: intermediate outputs, which are not traded as standard refinery products (e.g. vacuum residue) are always straightforward according to the allocation rules as defined: bottom products (output) made from bottom products (input) are always non-intended.

Specific considerations for low-sulphur marine fuels

The refinery's specific model parameters for the low-sulphur marine fuels were determined within the context of the EU JOULES project [JOULES, 2017]. The products **LSFO** (Low Sulphur Fuel Oil) and **VLSFO** (Very Low Sulphur Fuel Oil) come mainly from the vacuum residue, which is further processed in a hydrocracker. The HFO from the cracker is blended with other heavy oil products from the refinery to ensure a sulphur content of <= 1% resp. <= 0.5%. The hydrogen consumption in the cracker correlates with the desulphurisation requirement. The **ULSFO** (Ultra Low Sulphur Fuel Oil) with 0.1% sulphur, on the other hand, uses a larger proportion of middle distillate from atmospheric distillation with a lower sulphur content as feed. In the subsequent treatment in the hydrocracker, this (higher-value) intermediate product of the refinery requires less hydrogen than the VLSFO; the effects of higher-quality feed and lower hydrogen demand partially cancel each other and lead to similar results.

13.2 Detailed description of the emission factors for biogenic fuels

This chapter presents the method and results for emission factors for biofuels used in Europe. This is an update of emission factors previously created for EcoTransIT. The update and, in some cases, expansion is based on the specific input variables of the biofuel pathways (electricity consumption, fertilizer consumption, field emissions) and background data (electricity supply chain, etc.).

The following biofuel pathways are analysed:

- Biodiesel from rapeseed oil, soybean oil, palm oil, and used cooking oil (UCO)
- HVO from rapeseed oil and UCO
- Bioethanol from maize (EU), maize (US), wheat, sugar beet
- Biomethane as CNG and LNG from maize, wheat, grass (each as silage) as well as biowaste and manure

13.2.1 Emission factors for biofuels in Europe

The emission factors listed here for a selection of biofuels are updates of factors previously created for EcoTransIT by ifeu. They cover well-to-tank emissions and include the entire production chain, including upstream processes.

The calculation is based on a material flow model developed by ifeu in the Umberto 11 software. Updates relate in particular to the yield situation, fertilizer requirements and upstream chains for cultivated biomass, grid electricity and transport chains. In addition, more recent data on nitrous oxide emissions (N_2O) are taken into account for cultivation emissions. See also [Fehrenbach et al., 2025], [Fehrenbach et al., 2023].

Biodiesel/HVO

Raw materials and raw material mix

The European raw material mix for biodiesel refers to the year 2020 and can be found in [Fehrenbach et al., 2023]. More recent data can be found in [Flach et al., 2024]. The following trend can be observed:

- Palm oil is no longer counted toward RED obligations in many EU countries and is hardly found in the biofuel mix anymore.
- In contrast, the share of biodiesel from soybean oil has increased.
- Used cooking oil (UCO) and animal fat already achieved high shares before 2020 and have since stagnated at this level.
- So-called "advanced biofuels" are playing an increasingly important role, although there is considerable uncertainty about the actual origin and data quality for GHG calculations for biodiesel and HVO raw materials; these include:
- oil-containing wastewater from palm oil mills (POME), which is explicitly mentioned in Annex IX of RED III as a raw material for advanced biofuels, and
- free fatty acids from palm oil refining (PFAD for short), a by-product of palm oil production, not mentioned in Annex IX of RED III, but considered "advanced" in some EU countries; values for PFAD are given and discussed in the GREET model in chapter 13.2.2.

Table 83 shows the mix for biodiesel and HVO used in the EU.

Table 83: Proportions of the raw material mix for biodiesel and HVO used in the EU

	Rapeseed oil	Soybean oil	Palm oil	UCO
Biodiesel (FAME)	51.5%	9.6%	10.4%	28.6%
Hydrogenated vegetable oil (HVO)	65%			35%

Emissions factors for biodiesel and HVO

Table 84 shows the updated GHG emission factors for the different production stages.

Table 84: Break-down of GHG emission factors for biodiesel and HVO used in the EU (g CO_2e/MJ)

	FAME rape-seed oil	FAME soy-bean oil	FAME palm oil	FAME UCO	HVO rapeseed	HVO UCO
Processing	10.8	11.7	11.6	11.9	11.3	9.8
Cultivation	6.4	1.8	4.0	0.0	2.6	0
Fertilizer	9.7	1.2	2.2	0.0	3.5	0
Transport	2.2	11.5	5.6	5.4	6.2	5.2
GWP100	29.1	26.2	23.4	17.3	23.6	15.1

Bioethanol

Raw materials and raw material mix

For bioethanol the European raw material mix refers to the year 2020 and can be found in [Fehrenbach et al., 2023]. More recent data can be found in [Flach et al., 2024]. The following trends can be observed:

- Cereals, especially maize, continue to account for a large proportion of the raw mate-rials used; this also applies to the proportion of maize ethanol imported from the US.
- An increase can be observed in sugar cane, which played a rather minor role in the European bioethanol market until 2020.
- "Advanced biofuels" are having a much harder time in the bioethanol sector than for biodiesel/HVO. No ramp-up can be observed here.

Table 85: Proportions of the raw material mix for ethanol used in the EU

	Maize (EU)	Maize (US)	Wheat (EU)	Sugar beet (EU)
Share	32.7%	27.8%	32.3%	7.1%

Emission factors for bioethanol

Table 86: Break-down of GHG emission factors for bioethanol used in the EU (g CO_2e/MJ)

	Maize (EU)	Maize (US)	Wheat	Sugar beet
Conversion	15.00	12.30	13.66	10.04
Cultivation	3.31	6.36	3.28	2.02
Fertilizer	6.49	6.58	8.44	3.83
Transport	2.95	4.09	2.69	2.59
GWP100	27.80	29.30	28.10	18.50

Biomethane

Raw materials and raw material mix

Biomethane in Europe comes almost exclusively from domestic sources. Imports have not played a role to date.

The mix is based on data from EBA [Alberici et al., 2024]. The mix is dominated by Germany, the largest producer, which means a high proportion of maize and other crop-based biomass (all other important EU countries, on the other hand, rely more heavily on bio-waste and manure). Table 87 shows the estimated mix of substrates for biomethane production in the EU.

Table 87: Proportions of the raw material mix for biomethane used in the EU

	Biowaste	Manure	Maize (whole plant silage)	Wheat (Whole plant silage)	Grass (whole plant silage)
Share	12.5%	14.7%	48.5%	10.8%	13.3%

Emission factors for BioCNG and BioLNG

GHG emissions factors for Bio-CNG can be found in Table 88 and for Bio-LNG in Table 89.

Table 88: Break-down of GHG emission factors for biomethane (CNG) used in the EU (g CO_2e/MJ)

	Biowaste	Manure	Maize (whole plant silage)	Wheat (Whole plant silage)	Grass (whole plant silage)
Fertilizer production	0.00	0.00	7.03	13.19	24.60
Cultivation emissions	18.24	18.33	9.27	9.27	9.49
Fermenter	1.95	1.96	2.15	2.05	2.15
Biogas boiler	1.23	1.24	1.25	1.24	1.25
Upgrading	2.60	2.61	2.65	2.63	3.31
Compression	1.82	0.00	3.79	6.50	1.26
GWP100	23.9	22.2	24.0	32.8	39.9

Table 89: Break-down of GHG emission factors for biomethane (LNG) used in the EU (g CO_2e/MJ)

	Biowaste	Manure	Maize (whole plant silage)	Wheat (Whole plant silage)	Grass (whole plant silage)
Fertilizer production	0.00	7.02	0	24.60	13.18
Cultivation emissions	1.82	3.79	0.00	3.79	6.50
Fermenter	18.23	9.26	18.31	9.49	9.26
Biogas boiler	0.00	0.00	0.00	0	0
Upgrading	1.23	1.25	1.24	1.25	1.24
Liquefaction	5.80	5.91	5.83	5.91	5.86
GWP100	27.1	25.4	27.2	36.0	45.0

Discussion of changes compared to previous values

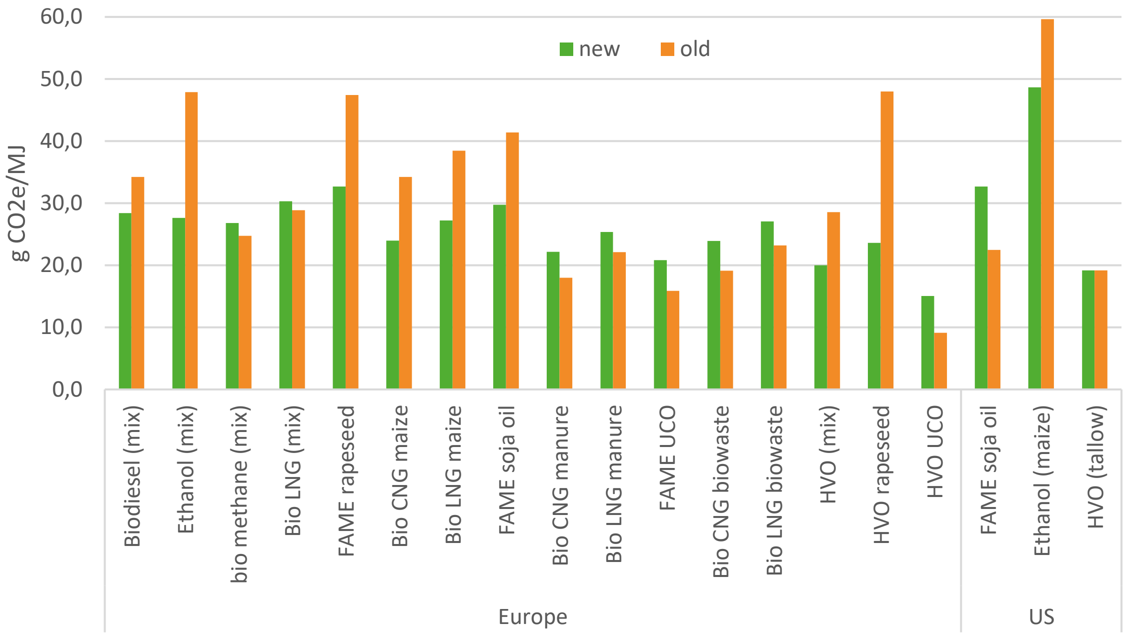
The emission factors for biofuels for the well-to-tank (WTT) life cycle stage are also determined here in accordance with the calculation principles of RED III Annex V Part C. What is not included are various credits that are permissible under the legislation and are intended to optimize certain practices in agriculture or animal husbandry in terms of climate impact but are not necessarily linked to the production of a biofuel.

This approach has also been applied to previous emission factors that ifeu has compiled for EcoTransIT World. For the version presented here, a number of changes have been made to the background data. Previous versions were based very closely on the background data from the so-called well-to-wheels study by the consortium of JRC, Eucar, and Concawe [Prussi, M. et al., 2020] and the BioEm study by the German Federal Environment Agency, which was also based on this [Fehrenbach, H., 2016]. However, some aspects of this data are no longer considered to be up to date. Various details have therefore been updated. The most significant changes are as follows:

- Emissions and consumption for grid-based electricity (EU mix) have been updated (331 g CO_2e/kWh for the reference period up to 2024). In the previous calculation, the GHG emission factor for electricity was taken from JRC, which was 789 g CO_2e/kWh.
- Adjustment of the specific energy consumption of biogas production by substrate; this is based on the detailed data from [Billig, 2016]. This differs significantly in some cases from the JEC data previously used in [Prussi, M. et al., 2020]: the electricity consumption of fermentation is now significantly higher than before for the substrate manure, while the specific consumption is slightly lower when using renewable raw materials.
- In general, the values for biomethane are slightly higher than those in the JEC study, as the latter does not take into account the diffuse methane emissions from the biogas plant. Therefore, the values determined here for biomethane from manure and biowaste are also slightly higher than the standard values of RED III.
- For cultivated biomass, the reduction in nitrous oxide emissions through fertilization has a reducing effect on the GHG balance.

For GHG emissions, these various factors result in an overall alignment of the different pathways: the emission factors for cultivated biomass, which have tended to be higher in the past, are falling slightly in some cases, while some of the waste-based biofuels are achieving slightly higher values. This is shown in.

Figure 28: Change in GHG emission factors of the updated values compared to the previous emission factors



The differences in non-GHG emission parameters vary greatly:

The emission factors are higher for SO_2, NMVOC and particulate matter. They are partly higher and partly lower for NO_x, N_2O and PEC. The reason for this is the changed electricity data, which, although significantly lower in GHG emissions, is in some cases higher than the previous data in the other parameters. This is reflected accordingly in the pathways with significantly higher electricity consumption (e.g., biomethane from manure or biowaste).

13.2.2 Emissions factors for the US from GREET

In addition to the updated emission factors for biofuels used in the EU, the emission factors from the US GREET model were considered for the international market and evaluated in terms of their comparability with the values calculated here.

A key difference here is that the GREET model follows a different allocation approach: unlike the RED method used for the emission factors above, which is based on allocation according to the energy content of co-products, GREET generally uses the credit method. As analyses by [Fehrenbach, H., 2016] show, this leads to similar results in many cases, but can also result in significant deviations in individual cases. In addition, the GREET model applies a number of additional credits specifically for biomethane (referred to as renewable natural gas, RNG, in GREET), which can be described as otherwise avoided burdens (avoidances). These credits are difficult to understand in some cases.

Table 90 lists the emission factors for greenhouse gas (GHG) emissions for various biofuels. They are listed without the credits, as these are not included in EcoTransIT. These and the resulting "net values" are shown separately.

Table 90: GHG emission factors for biofuels from the GREET model (g CO_2e/MJ)

Biofuel	Raw material	Emissions without credits [a)]	*ifeu values*	Credit for special co-effects	Credit for avoidance	Net emissions
Biomethane [b)]	Landfill gas	16.7			-1.0	15.6
	Animal waste (= manure)	17.8	20.4		-130	-112.4
	Sewage sludge	80.7		-30	-18	31.8
	Household waste	44.8	22.1	-116	-7	-78.4
Bioethanol	Corn (=maize)	48.7	28.5			48.7
	Sorghum	50.3				50.3
	Sugar cane	33.8				33.8
Biodiesel [c)]	Soybean	25.6	26.2			25.6
	Palm oil	28.4				28.4
	Canola (= rapeseed)	46.3	29.1			46.3
	Jatropha	50.1				50.1
	Camelina	32.2				32.2
	Animal fat	14.8				14.8
	Palm oil distillates (PFAD)	9.5				9.5
	UCO, imported	20.7				20.7

a) "Classic" co-product credit has already been applied here (e.g., rapeseed meal from rapeseed oil).

b) Designated as RNG in the GREET model

c) Referred to as biooil in the GREET model

Where data is available from the update carried out here, it is compared with the GREET values without credits. This is then discussed in detail.

Discussion of the GREET factors

Biomethane from landfill gas:

The emission factor of 16.7 g CO_2e/MJ appears valid. The gas occurs automatically and the energy expenditure consists of gas collection. A comparatively low credit for avoidance of 1.0 CO_2e/MJ is not particularly relevant. However, since gas collection and use actually avoid significant gas emissions, this low value is difficult to understand in view of the high credits in the following pathways.

Biomethane from animal waste, i.e., excrement, slurry, manure:

The emission factor of 17.8 g CO_2e/MJ also appears valid and corresponds well with the 20.4 CO_2e/MJ from the current update. The credit of 130 CO_2e/MJ is significant but is within the range reported by RED III for the avoidance of methane emissions from manure fermentation instead of direct use of manure.

However, such credits should be avoided in emission factors, as they consequently offset the benefits to the biofuel. However, the emission-avoiding performance takes place within the context of animal husbandry and should therefore also be credited to animal products.

Biomethane from sewage sludge:

The emission factor of 80.7 g CO_2e/MJ is incomprehensibly high. Incidentally, it is only partially reduced by credits. These are specified for "avoided energy and emissions" and for "fertilizer replacement." The latter is questionable given the limited use of sewage sludge as fertilizer.

This leaves 31.8 g CO_2e/MJ. Based on data from the well-to-wheel studies by JRC/Concawe/Eurcar [Prussi, M. et al., 2020], sewage sludge CNG without such deductions results in emissions well below 30 g CO_2e/MJ.

Biomethane from household waste:

While Europe is assumed to have separately collected and fermented biowaste, GREET uses total household waste fermentation here. In any case, the approaches are roughly comparable, as biowaste ultimately contains a higher proportion of fermentable material. The emission factor of 44.8 g CO_2e/MJ is double that for biowaste in the EU, which seems somewhat excessive but is not implausible given the increased effort involved and lower yield. However, massive credits of 123 g CO_2e/MJ are significant here. It is not clear how these can be explained. Presumably, avoided landfill is credited here. A necessary waste management improvement measure is thus credited to the "by-product" biogas. As with manure, such credits should be avoided in emission factors.

Bioethanol from corn:

The emission factor of 48.7 g CO_2e/MJ is within the range specified in Annex V of RED III for ethanol from maize (natural gas as process fuel in conventional plants) as a typical value. In this respect, the value is fundamentally plausible, even though the updated value for corn ethanol in this study is significantly lower at 28.5 g CO_2e/MJ. The earlier emission factor calculated by ifeu, at 34 CO_2e/MJ, already took improvements in the production chain into account. Lower field emissions (N_2O) and reductions in the fertilizer supply chain are the main contributors to the lower EU values.

Bioethanol from sorghum:

There are no comparative values available for this. However, it is plausible that sorghum, which has a slightly lower yield than corn, has a slightly higher emission value (50.3 CO_2e/MJ).

Bioethanol from sugar cane:

An emission value of 33.8 CO_2e/MJ is slightly higher than the values in RED III or [Prussi, M. et al., 2020], but these already assume very optimal production processes. For a generic emission factor, a value of over 30 CO_2e/MJ for sugar cane ethanol is plausible.

Biodiesel from soybean oil:

The emission values here are very similar. Two factors are particularly relevant for soy: 1) Field emissions, as little additional N fertilizer is applied here, and 2) The transport distance, which makes a greater contribution for the target market in Europe.

Biodiesel from palm oil:

An emission value of 28.4 g CO_2e/MJ represents an optimized production chain. Methane emissions from POME ponds are apparently excluded here. Under this assumption, the value is plausible, but it does not represent the standard in palm oil production.

Biodiesel from PFAD (palm oil fatty acid distillates):

An emission value of 9.5 g CO_2e/MJ clearly shows that PFAD is classified here as waste or residual material. This approach is controversial, as PFAD, as a by-product of palm oil refining, has a market value of around 80% of the target product palm oil. It is therefore not justifiable to assume that it is a residual material.

Correctly, an allocation should be made here, whereby PFAD, which has a similar calorific value, should also be assigned approximately the same emission factor as palm oil itself.

Biodiesel from canola (= rapeseed):

Canola is the Canadian name for rapeseed. The emission value of 46.3 CO_2e/MJ is quite high from today's EU perspective but corresponds well with the values of RED III. Here, too, as with corn ethanol, it can be assumed that lower values are possible, at least from a European perspective. However, it cannot be ruled out that the GREET value is still representative of the North American situation.

Biodiesel from jatropha and camelina:

There are no comparative values for either. Given the yield situation and the processing costs, the value for jatropha (50 CO_2e/MJ) seems plausible, but the value for camelina, at 32.2 CO_2e/MJ, seems very low. When compared to canola in particular, it is easy to see why camelina, which has a lower yield, has such low emissions. It can be assumed that reduced fertilizer use was taken into account here as a catch crop. This would need to be critically reviewed.

From the perspective of European data, however, 32.2 CO_2e/MJ for camelina is not implausible compared to 29.1 CO_2e/MJ for EU rapeseed diesel.

Biodiesel from animal fat (tallow) and used cooking oil (UCO):
Emissions of around 15 g CO_2e/MJ for biodiesel from animal fat and domestic UCO appear plausible and also correspond to the values for the EU. A surcharge of 5 g CO_2e/MJ for imported UCO is also plausible, as long-distance transport is common in this case.

Overall assessment of the GREET factors
The GREET data and calculation model contains a comprehensive amount of data and complex links and is rightly highly regarded among experts and is used extensively, particularly in North America.

The accounting methods essentially reflect globally accepted standards. However, there are also differences:

1. By-product allocation is carried out by means of credits, which, however, does not result in any significant differences from the EU method of calorific value allocation in the cases considered here.
2. Significant differences can arise from special credits, especially for biomethane. These should not be taken into account, as this would otherwise result in a significant imbalance between the two data sets.
3. The GREET data are more conservative in several aspects and lead to higher values for corn ethanol, for example, however, this is based less on the methodology than on the background data. There may be a time lag with older references in GREET than in the current update, but the GREET values may still be representative of the situation in North America.

13.3 Electricity emission factors at different voltage levels

With the 2026 update, EcoTransIT World has increased the number of countries with specific electricity mixes greatly, many countries formerly included into a bigger region are now modelled separately. A comparison of the previous and the new GHG emission factors of the electricity mixes is thus only possible for countries and regions which were already available in 2025 and are still included in 2026.

The table below shows a comparison of the GHG emission factors of the supply mixes at medium voltage level used for hubs and electric vehicles. For most countries/ regions, GHG emissions decrease as the amount of renewable electricity in the countries is increasing.

Table 91: Comparison of GHG emissions in gCO_2e per kWh of electricity at medium voltage level 2023/2021

Region	2023 [gCO_2e per kWh]	2021 [gCO_2e per kWh]
Africa	783	853
Australia	743	940
Austria	186	283
Belgium	161	191
Bosnia	840	902
Brazil	96	212
Bulgaria	467	600
Canada	174	192
Chile	332	542
China (including Hong Kong)	746	1041
Croatia	325	379
Cyprus	748	874
Czech Republic	486	640
Denmark	121	164
Estonia	328	788
EU27	294	355
Finland	63	184
France	74	89
Germany	412	472
Greece	443	510
Hong Kong	915	970
Hungary	319	369
Iceland	28	11
India	1040	1111
Iran	756	821
Ireland	296	376
Israel	749	846
Italy	341	435
Japan	569	639
Latvia	223	443
Lithuania	184	355
Luxembourg	299	303
Malta	489	511
Mexico	656	678
Middle East	910	767
Montenegro	501	519
Netherlands	289	394
Non-OECD America	220	305
Non-OECD Europe and Eurasia	668	731
Norway	23	17
Poland	762	948
Portugal	198	211

Romania	318	439
Russian Federation	639	737
Serbia	831	965
Slovakia	271	235
Slovenia	259	336
South Africa	1109	1317
South Korea	568	624
Spain	196	211
Sweden	27	26
Switzerland	79	89
Turkey	546	622
United Kingdom	222	297
United States	452	567
World	634	699

Source: ifeu calculations

Table 92: Energy and emission factors of the electricity supply mix 2023 for hubs/ electric vehicles) shows all emission factors for the electricity pre-chains of hubs/ electric vehicles (at medium voltage) for the different countries/ regions based on supply mixes including infrastructure emissions.

Table 92: Energy and emission factors of the electricity supply mix 2023 for hubs/ electric vehicles)

Region	PEC [kWh/kWh]	CO_2e [g/ kWh]	$CO_{2,\ fossil}$ [g/kWh]	NO_x [mg/kWh]	SO_2 [mg/kWh]	NMHC [mg/kWh]	PM10 [mg/kWh]
Africa	3.0	783	703	1659	744	131	3020
Albania	1.3	70	63	132	25	29	547
Algeria	3.2	734	658	909	987	44	160
Angola	1.9	303	266	2339	483	99	480
Argentina	2.4	381	329	579	653	54	300
Armenia	2.6	292	250	526	415	50	131
Australia	2.6	743	709	1283	151	69	1982
Austria	1.7	186	165	286	128	41	217
Azerbaijan	2.6	559	524	917	382	29	115
Bahrain	4.7	1115	966	1572	1791	141	535
Bangladesh	3.3	887	782	2149	1257	165	4470
Belarus	3.6	613	527	1070	891	78	369
Belgium	2.3	161	144	223	117	41	160
Benin	4.4	1007	885	2715	1569	146	647
Bolivarian Republic of Venezuela	1.6	130	114	271	183	47	227
Bosnia	2.8	840	807	1210	57	53	3752
Brazil	1.6	96	81	251	103	37	160
Bulgaria	3.0	467	441	445	99	52	1374
Cambodia	2.5	714	691	1006	51	66	1745
Cameroon	2.1	290	251	855	460	66	242
Canada	1.8	174	157	236	171	34	213
Chile	2.2	332	291	823	305	71	833

China (including Hong Kong)	2.3	746	692	1176	158	119	1695
Chinese Taipei	2.7	744	692	1121	331	107	773
Colombia	1.7	275	251	552	171	47	750
Costa Rica	2.1	70	60	175	96	52	399
Côte d'Ivoire	3.0	617	533	869	992	97	563
Croatia	2.1	325	298	506	144	47	1250
Cuba	4.0	1125	997	2676	1824	335	6927
Cyprus	2.8	748	670	930	1221	97	2639
Czech Republic	3.1	486	453	538	74	54	560
Democratic People's Republic of Korea	2.2	608	564	1199	164	110	721
Democratic Republic of the Congo	1.2	17	13	65	13	25	82
Denmark	1.5	121	107	268	53	38	150
Dominican Republic	2.9	846	762	1652	802	162	4238
Ecuador	1.9	286	252	764	440	95	731
Egypt	2.7	615	555	854	779	75	967
El Salvador	3.4	310	266	708	470	101	813
Estonia	2.7	328	302	486	170	79	637
Ethiopia	1.2	10	7	27	8	25	34
EU27	2.3	294	262	411	240	60	314
Finland	2.2	63	53	198	44	34	106
France	2.8	74	64	140	72	38	120
Georgia	1.6	177	150	315	251	34	78
Germany	2.1	412	377	557	123	52	395
Ghana	2.5	497	430	779	795	77	285
Greece	2.3	443	400	1143	338	70	700
Guatemala	3.3	460	405	1431	426	124	2763
Haiti	3.2	875	778	2132	1418	278	5877
Honduras	3.2	581	512	1547	923	204	3789
Hong Kong	3.0	915	829	1304	688	166	869
Hungary	2.7	319	291	465	174	50	1526
Iceland	2.9	28	24	66	18	54	78
India	2.9	1040	992	2167	146	132	4726
Indonesia	3.6	1036	990	1805	280	111	3398
Iran	3.3	756	678	958	1034	89	1374
Iraq	6.3	1651	1472	2749	2514	348	6189
Ireland	1.8	296	273	341	162	37	268
Israel	3.0	749	662	1059	907	108	967
Italy	2.2	341	300	359	360	58	303
Japan	2.5	569	526	742	319	98	475
Jordan	3.0	704	614	1265	1119	141	1225
Kazakhstan	2.8	938	850	1865	691	116	6383
Kenya	5.0	191	169	1195	264	129	763
Latvia	2.0	223	193	374	227	48	309
Lithuania	1.9	184	159	350	153	46	248

Luxembourg	2.4	299	267	505	150	62	293
Madagascar	2.6	694	628	3714	712	185	3739
Malaysia	2.6	793	740	1232	220	106	1557
Malta	2.3	489	421	504	671	62	360
Mexico	2.9	656	595	790	708	78	765
Middle East	3.7	910	795	1496	1465	174	2051
Montenegro	2.1	501	484	740	30	48	2369
Morocco	3.0	961	890	1879	316	154	6157
Mozambique	1.6	155	133	285	242	41	114
Myanmar	2.4	466	411	708	616	71	424
Nepal	1.2	10	7	26	8	24	33
Netherlands	1.8	289	264	347	175	49	259
New Zealand	2.7	130	111	249	165	55	166
Nigeria	2.9	610	543	426	885	33	83
Non-OECD America	1.8	220	191	460	309	61	496
Non-OECD Europe and Eurasia	3.2	668	599	1249	683	95	2022
Norway	1.1	23	19	44	11	23	42
Other non-OECD Asia	2.2	453	404	767	601	131	568
Pakistan	2.8	526	477	1223	530	95	2967
Paraguay	1.1	10	6	29	8	23	32
Peru	2.0	300	276	395	250	33	134
Philippines	4.0	1091	1048	1583	225	102	2516
Plurinational State of Bolivia	2.5	463	417	619	564	41	209
Poland	2.4	762	693	933	138	76	925
Portugal	1.8	198	168	569	270	50	252
Qatar	2.7	594	548	611	530	25	258
Romania	2.4	318	295	409	147	42	830
Russian Federation	3.1	639	565	1050	707	67	1074
Rwanda	2.6	575	528	1256	482	85	1058
Saudi Arabia	3.3	825	752	1313	963	147	2637
Senegal	3.7	1021	908	9760	1618	322	2011
Serbia	2.8	831	793	1520	105	54	11687
Singapore	2.3	563	488	829	865	77	346
Slovakia	2.9	271	242	382	141	49	418
Slovenia	2.3	259	241	298	84	42	468
South Africa	3.0	1109	1024	2495	185	92	8157
South Korea	2.9	568	523	1133	269	103	442
South Sudan	4.1	1173	1043	3141	1901	369	5516
Spain	2.2	196	171	460	249	54	240
Sri Lanka	2.3	632	579	1731	378	138	4934
Sudan	1.8	226	199	1633	359	89	982
Sweden	1.8	27	21	101	22	29	63
Switzerland	2.1	79	68	133	46	36	107
Syrian Arab Republic	3.5	919	807	1634	1482	208	3036
Thailand	2.8	576	531	1011	383	69	789
Tunisia	3.2	741	644	1159	1169	93	364
Turkey	2.3	546	503	791	220	63	3785

Uganda	1.4	51	42	364	77	38	214
Ukraine	3.2	423	383	855	213	79	4155
United Arab Emirates	2.9	467	425	498	490	33	253
United Kingdom	2.2	222	201	353	133	39	163
United Republic of Tanzania	3.4	728	631	1385	1168	111	445
United States	2.5	452	416	393	366	52	362
Uruguay	1.8	98	78	513	160	53	305
Uzbekistan	3.2	815	685	1027	1795	63	1745
Viet Nam	2.3	693	641	1173	199	116	1655
World	2.6	634	580	991	377	102	1235
Zambia	1.4	197	181	390	31	47	1329
Zimbabwe	2.9	964	898	1891	139	143	6653

Source: ifeu calculations

Table 93: Energy and emission factors of the electricity supply mix 2023 for trains (at pantograph)

Region	**PEC** [kWh/kWh]	**CO_2e** [g/ kWh]	**$CO_{2, fossil}$** [g/kWh]	**NO_x** [mg/kWh]	**SO_2** [mg/kWh]	**NMHC** [mg/kWh]	**PM10** [mg/kWh]
Africa	3.1	808	728	1715	3110	771	133
Albania	1.4	69	65	132	549	25	27
Algeria	3.4	768	692	950	144	1037	44
Angola	2.0	313	278	2446	479	505	100
Argentina	2.5	383	334	583	281	663	52
Armenia	2.7	305	263	551	115	438	50
Australia	2.8	786	753	1358	2084	159	70
Austria	1.8	194	174	298	207	135	40
Azerbaijan	2.8	586	552	962	97	402	28
Bahrain	5.0	1187	1031	1674	547	1912	148
Bangladesh	3.5	932	824	2263	4693	1325	171
Belarus	3.8	644	556	1126	366	941	79
Belgium	2.5	167	152	231	146	123	41
Benin	4.1	932	821	2517	579	1456	132
Bolivarian Republic of Venezuela	1.6	129	116	271	209	186	45
Bosnia	2.9	884	852	1274	3944	59	53
Brazil	1.7	95	83	255	142	105	35
Bulgaria	3.2	491	466	466	1433	103	52
Cambodia	2.6	744	722	1047	1803	52	66
Cameroon	2.1	292	255	869	223	469	65
Canada	2.0	181	166	245	203	180	33
Chile	2.3	348	307	867	860	322	73
China (including Hong Kong)	2.5	791	737	1248	1784	167	124
Chinese Taipei	2.8	790	738	1192	801	352	111
Colombia	1.8	286	264	577	768	179	46
Costa Rica	2.2	69	62	178	396	100	52
Côte d'Ivoire	3.1	638	554	899	563	1032	98
Croatia	2.2	337	312	526	1289	150	46

Cuba	4.2	1153	1024	2745	7099	1874	341
Cyprus	3.0	794	715	987	2793	1303	100
Czech Republic	3.3	513	481	567	572	77	55
Democratic People's Republic of Korea	2.3	627	585	1238	724	169	111
Democratic Republic of the Congo	1.2	14	12	63	63	12	23
Denmark	1.6	124	113	278	135	55	37
Dominican Republic	3.0	878	794	1718	4398	835	166
Ecuador	1.9	291	260	785	733	454	95
Egypt	2.8	626	568	870	969	798	74
El Salvador	3.6	322	279	738	830	493	103
Estonia	2.8	331	308	492	628	173	78
Ethiopia	1.2	6	6	22	11	7	22
EU27	2.5	307	277	429	308	253	61
Finland	2.4	62	56	205	88	45	33
France	2.9	74	66	142	102	75	37
Georgia	1.6	182	157	327	58	263	33
Germany	2.2	433	400	585	395	129	52
Ghana	2.6	517	450	810	274	831	77
Greece	2.4	459	417	1190	709	352	70
Guatemala	3.5	476	422	1489	2863	443	126
Haiti	3.4	904	806	2206	6073	1470	286
Honduras	3.2	573	507	1530	3739	915	199
Hong Kong	3.2	970	881	1382	900	731	174
Hungary	2.8	334	306	486	1590	182	49
Iceland	3.1	26	24	65	59	18	54
India	3.1	1078	1031	2248	4892	151	134
Indonesia	3.8	1093	1048	1906	3574	295	114
Iran	3.4	789	711	999	1418	1085	90
Iraq	5.8	1515	1354	2524	5675	2312	317
Ireland	1.9	308	287	354	258	169	36
Israel	3.1	794	704	1122	1006	965	112
Italy	2.3	356	316	374	297	379	58
Japan	2.7	600	558	782	481	337	101
Jordan	3.2	734	643	1320	1260	1171	144
Kazakhstan	3.0	982	892	1954	6685	725	119
Kenya	5.1	190	170	1209	752	267	128
Latvia	2.1	232	204	391	304	239	48
Lithuania	1.9	187	164	357	234	157	45
Luxembourg	2.5	311	280	527	285	157	62
Madagascar	2.8	733	666	3940	3948	755	193
Malaysia	2.7	834	782	1297	1623	231	109
Malta	2.5	512	444	527	356	708	62
Mexico	3.0	681	620	819	776	738	79
Middle East	3.9	942	826	1550	2109	1522	178

Montenegro	2.2	521	506	769	2458	30	48
Morocco	3.1	984	914	1927	6309	323	155
Mozambique	1.7	156	136	289	94	249	39
Myanmar	2.5	488	432	742	423	649	72
Nepal	1.2	6	6	21	10	6	22
Netherlands	1.9	303	280	364	251	185	49
New Zealand	2.8	133	117	258	152	173	55
Nigeria	3.0	631	564	437	63	919	32
Non-OECD America	1.9	224	197	471	490	318	61
Non-OECD Europe and Eurasia	3.4	699	630	1310	2106	718	97
Norway	1.2	20	19	40	21	10	22
Other non-OECD Asia	2.3	475	426	806	577	635	136
Pakistan	2.9	541	494	1263	3055	549	96
Paraguay	1.2	6	5	25	10	7	21
Peru	2.1	310	288	408	116	260	32
Philippines	4.2	1142	1100	1657	2618	235	104
Plurinational State of Bolivia	2.6	483	438	646	196	592	40
Poland	2.6	803	733	983	956	145	78
Portugal	1.9	203	176	591	240	282	49
Qatar	2.9	625	580	642	250	561	24
Romania	2.5	330	309	424	848	153	41
Russian Federation	3.3	669	595	1101	1108	744	67
Rwanda	2.6	588	543	1289	1067	496	84
Saudi Arabia	3.5	864	791	1376	2751	1012	152
Senegal	3.9	1060	946	10170	2072	1686	333
Serbia	2.9	868	831	1589	12240	109	53
Singapore	2.5	600	523	885	347	928	79
Slovakia	3.1	284	257	401	421	148	49
Slovenia	2.4	271	255	310	474	88	41
South Africa	3.1	1159	1073	2611	8534	192	93
South Korea	3.1	601	557	1203	447	286	106
South Sudan	4.3	1245	1110	3339	5851	2023	390
Spain	2.3	202	179	479	228	261	54
Sri Lanka	2.4	661	609	1817	5171	396	143
Sudan	1.8	224	200	1645	969	361	87
Sweden	1.9	24	21	101	42	22	28
Switzerland	2.3	79	71	135	89	47	35
Syrian Arab Republic	3.6	933	822	1662	3074	1511	209
Thailand	2.9	605	560	1063	810	403	70
Tunisia	3.3	758	661	1187	351	1201	93
Turkey	2.5	570	529	827	3963	230	63
Uganda	1.4	49	42	369	197	78	36
Ukraine	3.4	439	401	891	4337	222	80

United Arab Emirates	3.1	493	451	524	245	520	32
United Kingdom	2.3	229	210	364	147	138	38
United Republic of Tanzania	3.5	748	651	1426	436	1206	111
United States	2.7	476	441	411	359	387	52
Uruguay	1.9	99	81	533	296	166	53
Uzbekistan	3.4	862	727	1086	1831	1907	64
Viet Nam	2.4	729	677	1236	1728	209	120
World	2.7	667	612	1043	1282	398	104
Zambia	1.5	204	191	408	1388	31	47
Zimbabwe	2.9	979	914	1922	6757	140	143

Source: ifeu calculations

Regional mixes for China and the US

Table 94:Regional supply mixes for China and the US in 2023 (at pantograph)

	PEC [kWh/kWh]	CO_2e [g/kWh]	$CO_{2,\ fossil}$ [g/kWh]	NO_x [mg/kWh]	SO_2 [mg/kWh]	NMH [mg/kWh]	PM10 [mg/kWh]
CN_CSG	2.3	633	593	835	761	160	213
CN_CCG	2.3	887	836	1173	1148	94	311
CN_ECG	2.7	909	852	1191	1107	192	301
CN_NCG	2.5	1040	979	1370	1323	140	355
CN_NEG	2.4	953	899	1264	1247	90	336
CN_NWG	2.2	890	839	1185	1171	82	317
CN_SWG	1.6	339	318	452	424	59	126
US_WECC	2.5	450	416	387	331	366	50
US_MRO	2.6	579	549	474	576	279	53
US_TEXAS RE	2.7	546	504	408	330	506	53
US_SERC	3.1	554	510	497	362	501	57
US_RF	3.1	557	514	496	387	458	57
US_NPCC	2.6	346	310	296	104	475	44
US_ASCC	3.0	718	659	300	691	738	94
US_HICC	3.5	921	821	2089	2346	1482	289

Source: ifeu calculations

Table 95: Regional supply mixes for China and the US in 2023 (at medium voltage)

	PEC [kWh/kWh]	CO_2e [g/kWh]	$CO_{2,\ fossil}$ [g/kWh]	NO_x [mg/kWh]	SO_2 [mg/kWh]	NMHC [mg/kWh]	PM10 [mg/kWh]
CN_CSG	2.1	598	557	789	737	151	202
CN_CCG	2.1	836	785	1106	1100	90	294
CN_ECG	2.5	856	800	1123	1061	182	285
CN_NCG	2.4	979	918	1290	1264	133	336
CN_NEG	2.3	898	844	1191	1192	86	318
CN_NWG	2.1	838	788	1117	1120	79	300
CN_SWG	1.5	321	299	429	420	57	121
US_WECC	2.4	428	393	370	335	347	50
US_MRO	2.5	550	518	452	566	265	53
US_TEXAS RE	2.6	518	476	390	334	478	53
US_SERC	2.9	526	481	474	364	473	57
US_RF	2.9	529	485	473	388	433	57
US_NPCC	2.5	331	293	284	121	449	45
US_ASCC	2.8	681	622	711	674	696	92
US_HICC	3.3	872	775	1974	2233	1398	275

Source: ifeu calculations

14 References

Airbus. [2023]. *Airport and Maintenance Planning Documents*. Retrieved from https://aircraft.airbus.com/en/customer-care/fleet-wide-care/airport-operations-and-aircraft-characteristics/aircraft-characteristics

Alberici, S., Toop, G., Monchen, B., Peeters, S., and Peterse, J. [2024]. *Biogases towards 2040 and beyond. Guidehouse.* Retrieved from https://www.europeanbiogas.eu/biogases-towards-2040-and-beyond/

Allekotte, M., Biemann, K., Heidt, C., Colson, M., Knörr, W., and Kräck, Jan. [2024]. *Aktualisierung des Daten- und Rechenmodells: „Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland (TREMOD)" und der Datenbank „Mobile Maschinen und Geräte (TREMOD-MM)" 2022*. Retrieved from ifeu im Auftrag des Umweltbundesamts website: https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/76_2024_texte_tremod_.pdf

Amos, P., Dashan, J., Tao, N., Junyan, S., and Weijun, F. [2009]. *Sustainable Development of Inland Waterway Transport in China. Prepared for the World Bank and the Ministry of Transport (MOT), People's Republic of China*. Retrieved from http://siteresources.worldbank.org/EXTPRAL/Resources/china.pdf

Antonini, C., Treyer, K., Streb, A., van der Spek, M., Bauer, C., and Mazzotti, M. [2020]. Hydrogen production from natural gas and biomethane with carbon capture and storage – A techno-environmental analysis. *The Royal Society of Chemistry.*, (Vol. 4, No. 6, S. 2967–2986).

Argonne National Laboratory. [2023]. *GREET database 2022*.

Astorino, A. [2009]. *EUROCONTROL ETS Support Facilities and Fuel Estimator tool. Presentation*. Brussels: Eurocontrol.

Barthe, P., Chaugny, M., Roudier, S., and Sancho, L.D. [2015]. *Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas. European Integrated Pollution Prevention and Control Bureau (EIPPCB) of the European Commission's Joint Research Centre (JRC)*. Retrieved from BREF 2015 website: http://eippcb.jrc.ec.europa.eu/reference/BREF/REF_BREF_2015.pdf

BEIS. [2016]. *2016 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors*. London: Department for Business, Energy and Industrial Strategy (BEIS).

Billig, E. [2016]. *Assessment of technical and economic development potential of future and existing biomass-to-methane conversion processes: Dissertation. DBFZ Report German Biomass Research Center non-profit GmbH, Leipzig*.

BMVBS. [2011]. *Kompendium Nutzen-Kosten-Analyse (NKA) für Investitionen an Binnenschifffahrtsstraßen, Ausgabe 2011*. Berlin: Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS), Unterabteilung Wasserstraßen.

Boeing. [2021]. *767 Airplane Characteristics for Airport Planning*. Retrieved from https://www.boeing.com/content/dam/boeing/boeingdotcom/commercial/airports/acaps/767.pdf

Bussa, M., Jungbluth, N., and Meili, C. [2021]. *Life cycle inventories for long-distance transport and distribution of natural gas*.

BVB. [2009]. *The power of inland navigation. The future of freight transport and inland shipping in Europe 2010 – 2011*. Dutch Inland Shipping Information Agency (BVB).

Carstens, Stefan and Diener, Hans Ulrich. [2000]. *Güterwagen Band 2, Gedeckte Wagen - Sonderbauart.* MIBA-Verlag.

CCWG. [2015, June]. *Clean Cargo Working Group Carbon Emissions Accounting Methodology - The Clean Cargo Working Group Standard Methodology for Credible and Comparable CO_2 Emissions Calculations and Benchmarking in the Ocean Container Shipping Sector*. Retrieved from https://www.bsr.org/reports/BSR_CCWG_Carbon_Emissions_Methodology_2015.pdf

CEMT. [1992]. *Resolution No. 92/2 on New Classification of Inland Waterways*. Retrieved from http://www.internationaltransportforum.org/IntOrg/acquis/wat19922e.pdf

ch-aviation. [2023]. *ch-aviation*. Retrieved from https://www.ch-aviation.com/aircraft

Cox, B., and Althaus, H.-J. [2019]. *How to include non-CO_2 climate change contributions of air travel at ETH Zurich. On behalf of the Mobility Platform of ETH Zurich*. Retrieved from https://doi.org/10.3929/ethz-b-000409314

DB AG. [2008]. *Bahn-Umwelt-Zentrum: Energy and emission figures 2008*.

Dieselnet. [2016]. *Emission Standards International: IMO Marine Engine Regulations*. Retrieved from https://www.dieselnet.com/standards/inter/imo.php

dieselnet.com. [2016]. *DieselNet*. Retrieved from https://dieselnet.com/

Djibo, B. [2018]. *Overview of Air Cargo Services and Operations. Presentation in Zhengzhou, China, 5 September 2018*. Retrieved from https://www.icao.int/Meetings/IACD2018/Documents/S1_0%202nd%20Air%20Cargo%20China%20Setting%20the%20Scene%20by%20DATB%20ICAO.pdf

DLR, LBST, ifeu, and DBFZ. [2015]. *Identifizierung von Hemmnissen der Nutzung von LNG und CNG im schweren Lkw-Verkehr sowie Möglichkeiten zu deren Überwindung*. Retrieved from https://bmdv.bund.de/SharedDocs/DE/Anlage/G/MKS-Wissenschaftliche-Untersuchungen/studie-nutzung-lng-cng-schwere-lkw.pdf?__blob=publicationFile

Dobers, K., and Jarmer, J.-P. [2025]. *Guide for Greenhouse Gas Emissions Accounting at Logistis Hubs, Version 2.1*. https://doi.org/10.24406/publica-4159

Dobers, K., Perotti, S., Wilmsmeier, G., Mauer, G., Jarmer, J.-P., Spaggiari, L., Hering, M., Romano, S., and Skalski, M. [2023]. Sustainable logistics hubs: greenhouse gas emissions as one sustainability key performance indicator. *Transportation Research Procedia*, *72*, 1153–1160. https://doi.org/10.1016/j.trpro.2023.11.572

EC. [2019]. *Handbook on the external costs of transport*. Brussels: European Commission (EC), Directorate-General for Mobility and Transport.

EEA. [2019]. *EMEP/EEA Air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. Aviation (1.A.3.a, 1.A.5.b). Updated October 2019*. Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation/at_download/file

EEA. [2024]. *Number of ports and OPS facilities in the EU*. Retrieved from https://www.eea.europa.eu/en/analysis/maps-and-charts/number-of-ports-and-ops

energy.gov.il. [2016]. *Ministry of national infrastructure, energy and water resources (Israel): Fuel and the Environment*. Retrieved from http://energy.gov.il/English/Subjects/Subject/Pages/GxmsMniFuelAndTheEnvironment.aspx

EPA. [2021]. *Marine Compression-Ignition (CI) Engines, model years 2000-2022*. Retrieved from https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipmen

E-PRTR. [2019]. *Eurostat and the European Pollutant Release and Transfer Register (E-PRTR)*. Retrieved from https://ec.europa.eu/environment/industry/stationary/e-prtr/legislation.htm

esu services. [2024]. *Life cycle inventories of crude oil and natural gas extraction*. Retrieved from https://esu-services.ch/fileadmin/download/meili-2023-LCI%20for%20the%20oil%20and%20gas%20extraction.pdf

EU. [2023]. *Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation)*. Retrieved from https://eur-lex.europa.eu/eli/reg/2023/2405/oj/eng

Eurocontrol. [2023]. *Small emitters tool (SET) - 2022, Version 5.12.1 (9 January 2023)*. Retrieved from https://www.eurocontrol.int/tool/small-emitters-tool

Eurostat. [2023]. *European Energy Agency*. Retrieved from https://www.eea.europa.eu/themes/energy/renewable-energy/renewable-energy-in-europe-2022

Eurostat. [2025a]. Energy statistics - quantities, annual data (nrg_quanta). Retrieved 31 May 2025, from https://ec.europa.eu/eurostat/web/energy/database

Eurostat. [2025b]. *Yearly Energy Statistics – 2023 data "Final energy consumption in road transport by type of fuel: Gas oil and diesel oil (excluding biofuel portion) + Blended biodiesels + Natural gas + Biogases"*.

Fedlex. [2022]. *Verordnung über die Reduktion der CO_2-Emissionen (SR 641.711)*. Retrieved from https://www.fedlex.admin.ch/eli/oc/2022/311/de

Fehrenbach, H. [2016]. *Aktualisierung der Eingangsdaten und Emissionsbilanzen wesentlicher biogener Energienutzungspfade (BioEm)*.

Fehrenbach, H., Bürck, S., and Wehrle, A. [2023]. *The Carbon and Food Opportunity Costs of Biofuels in the EU27 plus the UK*. Retrieved from https://www.transportenvironment.org/wp-content/uploads/2023/03/ifeu-study-COC-biofuels-EU_for-TE-2023-03-02_clean.pdf

Fehrenbach, H., Köppen, S., and Wehrle, A. [2025]. *Report on typical GHG emission values for the cultivation of agricultural raw mate-rials for NUTS 2 regions or a more disaggregated level in Germany according to RED II. German Environment Agency. p. 151.* https://doi.org/10.60810/OPENUMWELT-7645

Fehrenbach, Horst, Liebich, Axel, Abdalla, Nabil, Biemann, Kirsten, Fröhlich, Thomas, and Simon, Balint. [2018]. *Life Cycle Inventories of Petroleum Refinery Operation*. ifeu.

Fitzgerald, Warren B., Howitt, Oliver J.A., Smith, Inga J., and Hume, Anthony. [2011]. Energy use of integral refrigerated containers in maritime transportation. *Energy Policy, Volume 39, Issue 4*. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0301421510009158

Flach, B., Lieberz, S., and Bolla, S. [2024]. *Biofuels Annual 2023. USDA FAS, The Hague*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_The%20Hague_European%20Union_E42024-0024.pdf

FOEN. [2015]. *Non-road energy consumption and pollutant emissions. Study for the period 1980 to 2050. Environmental studies no. 1519*. Retrieved from http://www.bafu.admin.ch/publikationen/publikation/01828/index.html

Fuel EU maritime. [2021]. *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0562

Graßl, H., and Brockhagen, D. [2007]. *Climate forcing of aviation emissions in high altitudes and comparison of metrics. An update according to the Fourth Assessment Report, IPCC 2007*. Hamburg.

Hapag Lloyd. [n.d.]. *Hapag-Lloyd containers*. Retrieved from https://www.hapag-lloyd.com/en/services-information/cargo-fleet/container.html

Hill, N., Amaral, S., Morgan-Price, S., Nokes, T., Bates, J., Helms, H., … Bauen, A. [2020]. *Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA* (No. 34027703/2018/782375/ETU/CLIMA.C.4). Retrieved from Ricardo Energy & Environment, ifeu - Institut für Energie und Umweltforschung, E4tech website: https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/2020_study_main_report_en.pdf

HPA. [2021]. *Onshore Power Supply (OPS) in the Port of Hamburg. Application by the Hamburg Port Authority AöR (HPA)*. Retrieved from https://sustainableworldports.org/project/port-of-hamburg-onshore-power-supply-ops/

IATA. [2022]. *Aviation Environment and Sustainability. Policy Update, August 2022*. Retrieved from https://www.iata.org/contentassets/139d686fa8f34c4ba7a41f7ba3e026e7/attachments-policy-team/e_and_s_policy_update-august_2022-final.pdf

IATA. [2023a]. *Air Cargo Market Analysis*. Retrieved from https://www.iata.org/en/iata-repository/publications/economic-reports/air-cargo-market-analysis-december-2023/

IATA. [2023b]. *Airline and Airport Code Search*. Retrieved from https://www.iata.org/en/publications/directories/code-search/

IATA. [2023c]. *IATA Airline and Location Codes*. Retrieved from https://www.iata.org/en/services/codes/

ICAO. [2012]. *ICAO Carbon Emissions Calculator. Version 5*. Montréal: International Civil Aviation Organisation (ICAO).

ICAO. [2023]. *Aircraft Type Designators*. Retrieved from https://www.icao.int/publications/doc8643/pages/search.aspx

ICCT. [2018]. *Policy update – Mexico heavy-duty vehicle emission standards*. Retrieved from www.theicct.org/sites/default/files/publications/Mexico-HDV-Emission-Standards_ICCT-Policy-Update_23022018_vF.pdf

ICCT. [2021]. *Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit*. Retrieved from https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf

IEA. [2022]. Global Methane Tracker 2022 – Analysis. Retrieved 16 October 2022, from https://www.iea.org/reports/global-methane-tracker-2022

IEA. [2023]. World Energy Statistics - Data product. Retrieved 31 October 2023, from IEA website: https://www.iea.org/data-and-statistics/data-product/world-energy-statistics

ifeu. [2003]. *Erarbeitung von Basisemissionsdaten des dieselbetriebenen Schienenverkehrs unter Einbeziehung möglicher Schadstoffminderungstechnologien – Weiterführung und Auswertung des UBA-FuE-Vorhabens 299 43 111*. im Auftrag des Umweltbundesamtes.

ifeu. [2015]. *Aktualisierung und Erweiterung des „Modells zur Berechnung der Luftschadstoffemissionen und des Kraftstoffverbrauchs von Verbrennungsmotoren in mobilen Geräten und Maschinen" TREMOD-MM Version 4 (2015) | Teilbericht im Rahmen der Aktualisierung des Modells*. im Auftrag des Umweltbundesamtes.

ifeu. [2021]. *ifeu refinery model*. Retrieved from https://www.ifeu.de/en/project/modellierung-von-raffinerie-und-petrochemischer-industrie/

ifeu and INFRAS. [2013]. *Aktualisierung der Emissionsberechnung für die Binnenschifffahrt und Übertragung der Daten in TREMOD. Im Auftrag des Umweltbundesamtes, FKZ 3711 45 105*. Retrieved from https://www.ifeu.org/verkehrundumwelt/pdf/ifeu%202014_Bericht%20Binnenschifffahrt%20TREMOD.pdf

ifeu and Öko-Institut. [2012]. *Entwicklung eines Modells zur Berechnung der Energieeinsätze und Emissionen des zivilen Flugverkehrs – TREMOD AV. UBA-Texte No. 48/2012*. Dessau-Roßlau: Umweltbundesamt (UBA) Germany.

IMO. [2009]. *Second IMO Greenhouse Gas Study 2009*. London: International Maritime Organisation (IMO).

IMO. [2015]. *Third IMO Greenhouse Gas Study 2014. Executive Summary and Final Report*. Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

IMO. [2019]. *IMO 2020. Taking bold action to clean up shipping emissions by reducing the sulphur content in ships' fuel oil.* Retrieved from https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/Sulphur%202020%20infographic%202%20page.pdf

IMO. [2020]. *Fourth IMO Greenhouse Gas Study. Final Report*. Retrieved from https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf

INFRAS. [2023]. *Handbuch für Emissionsfaktoren (HBEFA)*. Zürich.

integer.com. [2016]. *Industry Insight – International Diesel Emissions Regulation*. Retrieved from https://www.integer-research.com/industry-insight/emissions-legislation/

IPCC. [1999]. *Aviation and the Global Atmosphere. A Special Report of IPCC Working Groups I and III in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer*. Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press.

ISO 14083. [2023]. *Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations*.

Jackson, R. B., Saunois, M., Bousquet, P., Canadell, J. G., Poulter, B., Stavert, A. R., … Tsuruta, A. [2020]. Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources. *Environmental Research Letters*, *15*(7), 071002. https://doi.org/10.1088/1748-9326/ab9ed2

JOULES. [2017]. *joules project*. Retrieved from https://joules-project.eu/Joules/

KBA. [2001]. *Güterkraftverkehr deutscher Lastkraftfahrzeuge; Reihe 8; Heft 12*.

KBA. [2013]. *KBA and BAG: Verkehr deutscher Lastkraftfahrzeuge; VD5*.

Kienzler, H. P. [1998]. *Kapazitätsauslastung und Leerfahrten im Gütertransport; VDA Materialien zur Automobilindustrie, Heft 16*. Frankfurt am Main.

Knörr, W., and et al. [1999]. *Mobilitäts-Bilanz – Energieverbrauch und Emissionen im Personen- und Güterverkehr mit verschiedenen Verkehrsmitteln*.

Knowler, G. [2022]. *Belly cargo capacity makes slow return to global air freight*. Retrieved from https://www.joc.com/article/belly-cargo-capacity-makes-slow-return-global-air-freight_20220621.html

Koj, J., Wulf, C., Schreiber, A., and Zapp, P. [2017]. *Site-Dependent Environmental Impacts of Industrial Hydrogen Production by Alkaline Water Electrolysis*.

Kranke, A., Schmied, M., and Schön, A. D. [2011]. *CO_2-Berechnung in der Logistik - Datenquellen, Formeln, Standards*. Verlag Heinrich Vogel.

Kristensen, H. [2000]. *Energy consumption and exhaust emissions for various types of marine transport compared with trucks and private cars. Paper presented at ENSUS 2000 Conference, Newcastle, 4-6 September 2000*. Danish Shipowners Association.

Kristensen, H. O. H., and Hagemeister, C. [2011]. Environmental performance evaluation of ro-ro passenger ferry transportation. *Mercator*, (December).

Kusche, J. [2000]. *Transport-Ökobilanz von Deutschland nach Schweden. Diplomarbeit*. Berlin.

Lang, G. [2007]. *Passagierflugzeuge – Das aktuelle Typenbuch*. München: Scont-Verlag.

Lang, G. [2009]. *Flugzeuge – Die bekanntesten Passagierflugzeuge der Welt*. Fränkisch-Crumbach: Edition XXL.

Lauf, T., Memmler, M., and Schneider, S. [2023]. *Emissionsbilanz erneuerbarer Energieträger 2022 Bestimmung der vermiedenen Emissionen im Jahr 2022*. Retrieved from Umweltbundesamt website: https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/20231219_49_2023_cc_emissionsbilanz_erneuerbarer_energien_2022_bf.pdf

LCAG. [2014]. *Pallets, Container and Fleet*. Frankfurt am Main: Lufthansa Cargo AG (LCAG).

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., … Wilcox, L. J. [2020]. *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*.

Ligterink, N. E., van Gijlswijk, R. N., Kadijk, G., Vermeulen, R. J., Indrajuana, A. P., Elstgeest, M., … Traa, M. [2019]. *Emissiefactoren wegverker - Actualisatie 2019*. Retrieved from TNO website: https://publications.tno.nl/publication/34634132/zloCAn/TNO-2019-R10825.pdf

Lufthansa. [2014]. *Geschäftsbericht 2013*. Frankfurt am Main: Lufthansa AG.

Meili, C., Jungbluth, N., and Bussa, M. [2021]. *Life cycle inventories of crude oil and natural gas extraction*.

Meyers. [2003]. *Handbook of Petroleum Refining Processes, 3rd edition*.

Norway. [2020]. *Forskrift om endring i forskrift om begrensning i bruk av helse- og miljøfarlige kjemikalier og andre produkter (innføring av omsetningskrav til luftfart) (Amendment to Product Regulations)*. Retrieved from https://lovdata.no/dokument/LTI/forskrift/2019-04-30-555

Öko-Institut. [2009]. *Überarbeitung des Emissionsinventars des Flugverkehrs. Final report on behalf of the Umweltbundesamt*. Berlin: Umweltbundesamt (UBA) Germany.

Panteia. [2013]. *Contribution to impact assessment of measures for reducing emissions of inland navigation*. Retrieved from http://ec.europa.eu/transport/modes/inland/studies/doc/2013-06-03-contribution-to-impact-assessment-of-measures-for-reducing-emissions-of-inland-navigation.pdf

Prussi, M., Yuo, M., De Prada, L., Padella, M., and Edwards. [2020]. *JEC Well-To-Wheels report v5*. Retrieved from doi:10.2760/100379

Raghavendra Totamane. [2014]. *Air Cargo Demand Modeling and Prediction*. Retrieved from https://doi.org/10.1007/s11151-018-9631-2

Santoni, G., Lee, B., Wood, E., Herndon, S., Miake-Lye, R., Wofsy, S., McManus, B., Nelson, D., and Zahniser, M. [2011]. Aircraft Emissions of Methane and Nitrous Oxide during the Alternative Aviation Fuel Experiment. *Environmental Science & Technology*, *45*, 7075–7082. https://doi.org/10.1021/es200897h

Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., … Zhuang, Q. [2020]. The Global Methane Budget 2000–2017. *Earth System Science Data*, *12*(3), 1561–1623. https://doi.org/10.5194/essd-12-1561-2020

Scandria. [2012]. *Benchmarking of ferry and RoRo transport for the development of "green corridors for freight transport". Baltic Sea Region Project #26 "Scandinavian-Adriatic Corridor for Growth and Innovation"*. Ministry of Energy, Infrastructure and State Development, Mecklenburg-Vorpommern.

SFC. [2024]. *Clean Cargo Ocean Containership Greenhouse Gas Emission Intensity Calculation Methods*. Retrieved from https://www.smartfreightcentre.org/en/skills/library/clean-cargo-emissions-calculation-method/

Skailark. [2023]. *Aviation costs, revenue and emissions intelligence*. Skailark GmbH.

Smart Freight Centre. [2023]. *Global Logistics Emissions Council Framework. For Logistics Emission Accounting and Reporting. Version 3.0.*

Smart Freight Centre. [2024]. *Global Logistics Emissions Council (GLEC) Framework for Logistics Emissions Calculation and Reporting. Version 3.1*.

Smith, C., Nicholls, Z. R. J., Armour, K., Collins, W., Forster, P., Meinshausen, M., Palmer, M. D., and Watanabe, M. [2021]. *The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity*. Retrieved from Cambridge University Press website: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf

Spire. [2023]. *ADS-B flight data - Aviation data set*. Retrieved from https://spire.com/spirepedia/ads-b/

Statista. [2018]. *Freight-tonne kilometers of main cargo aircraft and aircraft with combined passenger and freight capacity as a share of world total in 2016 and 2036*.

Statista. [2022]. *Freight-tonne kilometers share of air cargo traffic worldwide in 2019 by type*.

STC-Nestra. [2018]. *GHG emission factors for IWT. Final report, 2 May 2018*. Retrieved from https://www.smartfreightcentre.org/pdf/GLEC-report-on-GHG-Emission-Factors-for-Inland-Waterways-Transport-SFC2018.pdf

Tassou, S.A., De-Lille, G., and Ge, Y. T. [2009]. Food transport refrigeration - Approaches to reduce energy consumption and environmental impacts of road transport. *Applied Thermal Engineering, Vol. 29 No 8-9 pp. 1467–1477*.

ThermoKing. [2014]. *ThermoKing Webseite*. Retrieved from https://www.thermoking.com/news-article.aspx?id=396

TNO. [2011]. *Environmental and Economic aspects of using LNG as a fuel for shipping in the Netherlands*.

TNO. [2017]. *Emissions testing of two Euro VI LNG heavy-duty vehicles in the Netherlands: tank-to-wheel emissions*.

transportpolicy.net. [2016]. *Fuels: Diesel and Gasoline in the US, Australia and Canada*. Retrieved from https://www.transportpolicy.net/

trend news agency. [2013]. *Iranian dangerous fuels with 180 to 8000 ppm sulphur, trend news agency 2013*. Retrieved from http://en.trend.az/iran/2106825.htm

UIC. [2009]. *UIC Energy and CO_2 Database*.

UK Government. [2024]. *The Renewable Transport Fuel Obligations (Sustainable Aviation Fuel) Order. UK Statutory Instrument 2024 No. 1187*. Retrieved from https://www.legislation.gov.uk/uksi/2024/1187/contents/made

UN. [2025]. *UN database - Energy Statistics Database – 2022 data*.

UNEP. [2007]. *Opening the door to cleaner vehicles in developing and transition countries: the role of low sulphur fuels. UNEP (PCFV)*. Retrieved from http://www.unep.org/transport/pcfv/pdf/sulphurreport.pdf

US EPA. [2024]. *Motor Vehicle Emission Simulator: MOVES5*. Retrieved from Office of Transportation and Air Quality. US Environmental Protection Agency website: www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves

Van de Reyd, and Wouters. [2006]. *Air Cargo Density Research*. Retrieved from https://aerlinesmagazine.wordpress.com/2006/03/13/air-cargo-density-research/

Wagner vom Berg, B., Arens, U., and Kühne, U., Stenau, J. P. [2023]. *Klimafreundliche Kühlsysteme für den Straßengüterverkehr*. Retrieved from NOW website: https://www.now-gmbh.de/wp-content/uploads/2023/07/NOW-Studie_Klimafreundliche-Kuehlsysteme-fuer-den-Strassengueterverkehr.pdf

Weidema, B. P., Bauer, Ch., Hischier, R., Mutel, Ch., Nemecek, T., Reinhard, J., Vadenbo, C. O., and Wernet, G. [2013]. *The ecoinvent database: Overview and methodology, Data quality guideline for the ecoinvent database version 3*. Zürich: Ecoinvent Center.

Whelan, S. [2022]. *Full bellies again for air cargo, but some players still hungry for freighters*. Retrieved from https://theloadstar.com/air-cargo-capacity-is-back-as-bellies-return-but-freighter-use-remains-high/

Williams, E., Lerner, B., and Murphy, P. [2008]. *Determination of Emission Factors from Commercial Marine Vessels. 17th International Emission Inventory Conference, Portland OR, June 03, 2008*. Retrieved from http://www3.epa.gov/ttnchie1/conference/ei17/sessio uropa sams_pres.pdf

World Bank. [2019a]. *GDP Deflator (annual %), World Bank national accounts data, and OECD National Accounts data files, online database*. Retrieved from https://data.worldbank.org/indicator/NY.GDP.PCAP.CD

World Bank. [2019b]. *GDP per capita (current US$), World Bank national accounts data, and OECD National Accounts data files, online database*. Retrieved from https://data.worldbank.org/indicator/NY.GDP.PCAP.CD

World Port Sustainability Program. [2024]. *Ports using OPS*. Retrieved from https://sustainableworldports.org/ops/ops-installed/ports-using-ops/

Yang, J., Johnson, K. C., Durbin, T. D., Karavalakis, G., and Cocker, D. R. [2017]. *Marine Scrubber Efficiency and NO_x Emission from Large Ocean Going Vessels. Presentation at the 2017 International Emissions Inventory Conference, August 14-18, Baltimore MD*.

Abbreviations

Abbreviation	Full Word	Explanation
AEL	Alkaline Electrolysis	Method of producing hydrogen through water electrolysis.
AIS	Automatic Identification System	Tracking system used on ships and vessels
API	Application Programming Interface	Set of rules and protocols that allow different software applications to communicate
AR5	Fifth Assessment Report	Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC)
BC	Bulk Carrier	Type of cargo vessel
BEV	Battery Electric vehicle	Type of electric vehicle
BLE	Bundesanstalt für Landwirtschaft und Ernährung	Federal Agency for Agriculture and Food (Germany)
BREF	BAT Reference Document	Document that describes the best available techniques (BAT).
CC	Container Carrier Vessel	Cargo vessels specifically designed for the transport of containers.
CC or CCWG	Clean Cargo	Initiative that provides annual CO_2 emission factors based on fuel consumption data from shipping companies.
CCNR	Central commission for the navigation of the rhine	International organization that sets standards and regulations for navigation on the Rhine and other European inland waterways.
CCR	Carbon capture and recycling	Technology where CO_2 is captured and then recycled.
CCS	Carbon Capture and Storage	Technology used to capture and store carbon dioxide (CO_2)
CCU	Carbon capture and utilization	Process where CO_2 is captured and used for beneficial purposes instead of being stored or recycled.
CCWG	Clean Cargo (earlier called „Clean Working Group“)	Initiative focused on reducing the environmental impact of the shipping industry.
CEMT	Central European Motorways of the Sea Transport	Classification system used for waterways, typically related to the capacity and characteristics of inland waterway transport systems in Europe.
CH4	Methane	Greenhouse gas
CNG	Compressed Natural Gas	Fuel for vehicles
CO_2	Carbon dioxide	Greenhouse gas
CO_2e	Carbon dioxide equivalent	Greenhouse gas emissions as CO_2-equivalent
CoDi	Collection and delivery rounds	Logistics tours where goods are picked up or delivered at multiple locations along a vehicle's route.
CORINAIR	CORe INventory of AIR emissions	Programme to establish an inventory of emissions of air pollutants in Europe initiated by the European Environment Agency (EEA)
CORSIA	Carbon offsetting and reduction scheme for international aviation	Global scheme established by the International Civil Aviation Organization (ICAO) to reduce the carbon emissions of international aviation.
CSRD	Corporate sustainability reporting directive	Directive adopted by the European Union aimed at improving and standardizing sustainability reporting by companies
csv	comma-separated values	Format used for storing tabular data

DAF	Distance Adjustment Factor	Factor used to adjust the environmental impact or emissions of a transportation or logistics operation based on the distance travelled
DB	Deutsche Bahn	German railway company.
DWT	Dead Weight Tonnage	Total weight a vessel can safely carry, including cargo, fuel, crew, and provisions.
ECA	Emission Control Area	Defined geographical area where stricter regulations on air pollutants are enforced.
EEA	European Environment Agency	Agency of the European Union responsible for providing sound, independent information on the environment.
EER	Energy Efficiency Ratio	Factor used to compare the energy consumption of battery electric vehicles (BEVs) or fuel cell electric vehicles (FCEVs) to the energy consumption of conventional vehicles, such as diesel trucks.
EMEP	European Monitoring and Evaluation Programme	Cooperative effort between European countries to monitor and assess air pollution across Europe
EN	European Norms	Technical standards developed by the European Committee for Standardization (CEN).
EPA	Environmental Protection Agency	U.S. government agency responsible for regulating and enforcing national standards for environmental protection.
ERF	Effective Radiative Forcing	Measure of how greenhouse gases, aerosols, and contrails impact Earth's energy balance and climate change.
ETF	Empty trip factor	Relation of vehicle/vessel-km running empty and km loaded
ETW	EcoTransIT World (abbreviation for Ecological Transport Information Tool)	Emission calculation software developed by IVE mbH
EU	European Union	
EU SECA	European union sulphur emission control area	Designated area within the European Union where stricter regulations on the sulphur content in marine fuels apply.
EWF	Emission Weighting Factor	Measures the climate impact of aviation emissions at high altitudes
EWI	EcoTransIT World Initiative	Group of EcoTransIT World users to support the tool
FAME	Fatty acid methyl ester	Type of biodiesel produced through the chemical process known as transesterification.
FCEV	Fuel cell electric vehicle	Type of electric vehicle that uses a fuel cell to generate electricity, typically using hydrogen as the fuel.
FCL	full container load	Shipment large enough to fill an entire container
FEU	Forty-foot equivalent	Unit for container transport
FSU	Former Soviet Union	Group of countries that were part of the Soviet Union before it dissolved in 1991.
FTL	Full truck load	Shipment that fills an entire truck
g	gram	Unit of mass
GC	General cargo ship	Vessels designed to carry general cargo
GCD	Great circle distance	Transport distance determined as the shortest distance between any two points measured along the surface of a sphere

GCWR	Gross combined weight rating	Total maximum weight of a vehicle and its cargo.
GDP	Gross Domestic Product	Measure of the total economic output of a country
GHG	Greenhouse gases	Sum of greenhouse effecting gases, which include CO_2, N_2O, CH_4 and cooling gases.
GIS	Geographic information system	Technology is used to capture, store, analyse, manage, and visualize geographic data.
GLEC	Global Logistics Emissions Council	A program that develops global guidelines for calculating and reporting logistics greenhouse gas emissions; published the GLEC Framework
GREET	Greenhouse gases, regulated emissions and energy use in transportation	Tool to model and assess the environmental impacts of transportation fuels and vehicle technologies.
GSE	Ground Support Equipment	Vehicles and equipment used at airports
GVW	Gross vehicle weight	Total weight of a vehicle
GVWR	Gross vehicle weight rating	Maximum allowable total weight of a vehicle when fully loaded.
GWP	Global Warming Potential	Measures the impact of greenhouse gas on global warming.
Gtkm	Grosse tonne-kilometre	Unit of measure for transport activity in rail method; see also tkm
GTW	Gross Tonne Weight	Total weight of object
h	Hour	Unit of time
H2	Hydrogen	
HBEFA	Handbook Emission Factors for Road Transport	Standardized emission factors based on different vehicle types, fuel types, and driving conditions.
HC	Hydrocarbon	
HEFA	Hydro processed Esters and Fatty Acids	Process used to produce Hydrotreated Vegetable Oil (HVO)
HFO	Heavy fuel oil	Heavy fuel oil for marine vessels.
HGV	Heavy goods vehicle	HGV is used to categorize vehicles in relation to various external costs, such as accidents and noise.
HO	hub operation	
HOC	hub operation categories	Group of hub operations that share similar characteristics
HSD	High-Speed Diesel	Classifications of diesel engines used in maritime vessels
HSFO	High-Sulphur Fuel Oil	Type of heavy fuel oil; subtype of HFO (heavy fuel oil)
HSHFO	High-Sulphur Heavy Fuel Oil	Type of fuel oil; heavier grade of HSFO; subtype of HFO (heavy fuel oil)
HVO	Hydrotreated vegetable oil	Type of renewable diesel fuel.
IATA	International Air Transport Association	Trade association for the world's airlines
ICT	Information and Communication Technology	Systems that enable the collection, processing, and exchange of data related to transport operations.
IEA	International Energy Agency	Agency that promotes energy security, economic growth, and sustainability
ifeu	Institute for Energy and Environmental Research	Research institute focusing on sustainable energy, environmental protection, and life cycle analysis.

iLUC	Indirect land use change	Environmental impact caused by changing land use patterns indirectly due to the production of biofuels or other products.
IML	Institute for Material Flow and Logistics	Part of the Fraunhofer Society for the Advancement of Applied Research.
IMO	International Maritime Organization	Specialized agency of the United Nations responsible for regulating shipping.
IPCC	Intergovernmental Panel on Climate Change	UN body that assesses and provides scientific information on climate change, its causes, impacts, and solutions.
ISAE	International Standard on Assurance Engagement	Guidelines for auditors to ensure the quality and reliability of non-financial information, such as sustainability reports.
ISO	International Organization for Standardization	International body that develops and publishes standards for a wide range of industries to ensure quality, safety, and efficiency.
IVE	Ingenieursgesellschaft für Verkehrs- und Eisenbahnwesen mbH	Consulting and software development company which provides the product EcoTransIT World
IWT	Inland waterways transport	Transportation of goods or passengers via navigable inland waterways
JSON	JavaScript Object Notation	Text-based format used for storing and transporting data.
kg	Kilogram	Unit of mass
km	Kilometre	Unit of distance
kW	Kilowatt	Unit of Power
l	Liter	Unit of volume
lbs	pounds	unit of weight
LCA	Life Cycle Assessment	Method used to evaluate the environmental impact of a product or service from its creation to its disposal.
LCI	Life Cycle Inventory	Collection and analysis of data related to the inputs and outputs of a product's life cycle.
LCV	Light Commercial Vehicles	Vehicles used for transporting goods or passengers, typically with a gross vehicle weight (GVW) up to 3.5 tons.
LFO	Light Fuel Oil	Type of fuel used in marine engines
LNG	Liquefied natural gas	Type of fuel
LPG	Liquefied petroleum gas	Type of fuel
LSFO	Low Sulphur Fuel Oil	Type of fuel used in marine engines
LSP	Logistics Service Provider	Freight forwarding company
LTL	Less-than-truckload	Shipping of smaller freight loads that don't fill an entire truck
LTO	Landing and Take-Off (Cycle)	Phase of an aircraft's flight where it is either landing or taking off from an airport
M	Mass	
m	Meter	Unit of length
MARPOL	International Convention for the Prevention of Pollution from Ships	Global treaty aimed at reducing pollution from ships to protect the marine environment.
MDO	Marine diesel oil	Distillate marine fuel with a typically low sulphur content.
mg	milligram	Unit of mass
MGO	Marine Gas oil	Distillate marine fuel blended with residual fuels, with a typically low sulphur content.

MHE	Material Handling Equipment	Tools and machinery used for moving, storing, controlling, and protecting materials
MJ	Megajoule	Unit of energy
MOVES	Motor Vehicle Emission Simulator	Tool developed by the U.S. EPA to estimate vehicle emissions and energy consumption.
MSD	Medium-Speed Diesel	Classifications of diesel engines used in maritime vessels
MTOW	Maximum Take-Off Weight	Maximum weight at which an aircraft is allowed to take off, including its own weight, fuel, passengers, cargo, and other necessary items.
MZFW	Maximum Zero-Fuel Weight	Maximum weight of an aircraft excluding its fuel.
N_2O	Nitrous oxide	Greenhouse Gas
Nm	Nanometre	Unit of length
NMHC	Non-methane hydrocarbons	Exhaust emission / air pollutant
NO_x	nitrogen oxides	Exhaust emission / air pollutant
Ntkm	Net tonne-kilometre	Unit of measure for rail freight method; see also tkm
OAG	Official Airline Guide	Database of scheduled flight information used in aviation analysis.
OECD	Organisation for Economic Co-operation and Development	International organizations with 38 member countries aimed at promoting policies to improve global economic and social well-being.
PEM	Proton Exchange Membrane electrolysis	Advanced method of producing hydrogen through water electrolysis.
PM	Particulate Matter	Tiny solid or liquid particles suspended in the air.
PME	Palm oil methyl ester	
POME	Palm oil mill effluent	Wastewater from palm oil mills
ppm	Parts per Million	
PPP	Purchasing power parity	Unit of measurement
RED	Renewable Energy Directive	European Union legislation aimed at promoting the use of renewable energy sources across the EU.
REff	Resource Efficiency at Logistics Sites	GHG Assessment Tool for Logistics Locations
REST	Representational State Transfer	Architectural style used for designing networked applications
RFI	Radiative Forcing Index	Measure used to evaluate the climate impact of certain emissions.
RFS	Road or Train Feeder Service	Information about transportation services that connect to the main flight.
RME	Rapeseed oil methyl ester	
RNG	Renewable Natural Gas	Type of biogas produced from organic waste materials.
RoRo	Roll-on/roll-off vessel	Shipping method
SAF	Sustainable Aviation Fuel	Type of jet fuel made from renewable resources
SBB	Schweizerische Bundesbahnen	Swiss Federal Railways
SBTi	Science Based Targets initiative	Guidelines for setting science-based goals.
SCAC	Standard Carrier Alpha Code	Code used to identify shipping carriers in the United States

SCR	Selective catalytic reduction	Technology to reduce emissions of diesel engines
SET	Small Emitters Tool	Empirical method used to estimate fuel consumption
SFC	Smart Freight Centre	Non-profit organization focused on reducing the environmental impact of freight transportation.
SFD	Shortest feasible distance	Transport distance determined as the distance achievable by the shortest practical route available.
sFTP	Secure File Transfer Protocol	Method used to securely transfer files
SMR	Steam Methane Reforming	Process used to produce hydrogen
SNCF	Société Nationale des chemins de fer	French national railway company
SO_2	sulphur dioxide	Exhaust emission / air pollutant
SOAP	Simple Object Access Protocol	Protocol used for exchanging structured information in the implementation of web services.
SSD	Slow-Speed Diesel	Classifications of diesel engines used in maritime vessels
T	Tonne	Metric tonne, unit used in EcoTransIT World for the freight mass
TC	transport chain	
TCE	transport chain element	Part of the transport chain
TEU	Twenty-foot equivalent unit	Unit for container transport
TJ	Terajoule	Unit of energy
tkm	Tonne kilometre	Tonne kilometre of freight; also: Ntkm (in distinction to Gtkm)
TNO	Technisch Nederland Onderzoek	Research organization in the Netherlands
TO	transport operation	
TOC	transport operation category	Group of transport operations that share similar characteristics
TREMOD	Transport Emission Model	Tool used to estimate emissions from various transport modes
TTW	Tank-to-Wheel	Emissions from vehicle/hub operation, called operational GHG emissions in ISO 14083
UCO	Used Cooking Oil	Type of waste oil
UCOME	UCO methyl ester	Methyl ester based on UCO
UIC	Union Internationale des Chemins de fer	International organization that standardizes railway operations
UK	United Kingdom	Country
ULCV	Ultra Large Container Vessel	Largest types of container vessels
ULSFO	Ultra-low sulphur fuel oil	Marine fuel with a sulphur content below 0.1%.
UN	United Nations	International organization
USA	United States of America	Country
UTC	Coordinated Universal Time	Primary time standard
VLCC	Very large crude carrier	Class of oil tankers
VLSFO	Very low sulphur fuel oil	Type of marine fuel with a sulfur content of 0.5% or lower
Wh	Watt-hour	Unit of energy consumption over an hour
WTT	Well-to-Tank	Emissions from upstream processes, called energy provision GHG emission in ISO 14083

WTW	Well-to-Wheel	Emissions from vehicle/hub operation and energy provision processes, called total GHG emissions in ISO 14083
XML	eXtensible Markup Language	Text-based format used for storing and transporting data.

15 Document writing

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