

EcoTransIT World

Environmental Methodology and Data Update 2023

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General Contact

Ingenieurgesellschaft für Verkehrs- und Eisenbahnwesen mbH Consulting Company for Traffic and Railway Engineering Ltd. Lützerodestr. 10, 30161 Hannover, Germany

EcoTransIT World Consulting Team

VL

+49 511 897668 - 18 |19 | 28

info@ecotransit.org

In Cooperation with



Infras AG – Consulting, Analysis and Research Berne, Switzerland



Ifeu – Institut für Energie- und Umweltforschung Heidelberg, Germany



Fraunhofer Institute for Material Flow and Logistics IML Dortmund, Germany

Responsibilities

Topic	Contact	Contact Address
Truck, Train, Energy Supply	Kirsten Biemann, ifeu	kirsten.biemann@ifeu.de
	Wolfram Knörr, ifeu	wolfram.knoerr@ifeu.de
	Christoph Heidt, ifeu	christoph.heidt@ifeu.de
Sea ship	Benedikt Notter, INFRAS	benedikt.notter@infras.ch
Inland ship	Benedikt Notter, INFRAS	benedikt.notter@infras.ch
	Christoph Heidt, ifeu	christoph.heidt@ifeu.de
Aircraft	Benedikt Notter, INFRAS	benedikt.notter@infras.ch
Logistic Sites	Kerstin Dobers, Fraunhofer IML	Kerstin.Dobers@iml.fraunhofer.de
Business Solutions,	Ralph Anthes, IVE	consulting@ecotransit.org
Routing, GIS-Data,	Alena Schmidt, IVE	
	Cristina Diaz-Cereceda, IVE	
	Malte Borschel, IVE	
	Lisa Lange, IVE	

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Disclaimer

This current version of the methodology report is including text parts which are historically based on the assumptions of the EN 16258 and newer parts which are already aligned with the ISO 14083. Currently the calculation of EcoTransIT World is not EN 16258 compliant, because the new conversion factors from the ISO 14083 are applied (and not the factors from the annex A). A complete ISO 14083 compliant version shall be available within the year 2023.

Foreword

The EcoTransIT Initiative (EWI) is an independent industry driven platform for carriers, logistics service providers and shippers dedicated to maintain and develop a globally recognized tool and methodology for carbon footprints and environmental impact assessments of the freight transport sector.

In line with its vision to increase transparency on the environmental impact of the freight transport and to demonstrate the continuous improvement of EcoTransIT methodology and EcoTransIT World (ETW) calculator, EWI members have commissioned their scientific and IT partners to provide an updated methodology report. The methodology was already embedded in the calculator. So far it followed the guidelines of the standard EN 16258 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services" and integrates latest research available for the air pollutants.

There are over 100 companies' member of the EWI. A complete EWI member and user list can be found at the website https://ecotransit.org

These members also thank their scientific and IT partners - INFRAS Berne, ifeu Heidelberg, Fraunhofer IML Dortmund and IVE Hannover - for their continuous support to the vision of EWI.

Introduction 1

Background and task 1.1

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 Fifth Assessment Report from the Intergovernmental Panel on Climate Change, 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.

EcoTransIT World means Ecological Transport Information Tool – worldwide (ETW). It is a free of charge internet application, which shows the environmental impact of freight transport – for any route in the world and any transport mode. More than showing the impact of a single shipment, it analyses and compares different transport chains with each other, thus making evident which solution has the lowest impact.

For professional users, ETW offers dedicated services that allow companies to calculate large numbers of shipments at once without manual handling efforts. It provides a customized interface based on individual customer's operational data and answering its needs and requirements. Thus, with ETW Business Solutions the corporate data warehouse can be filled with all information required to realize specific environmental reports, regional inventories, establish carbon reporting or provide carbon accounting benchmarks efficiently.

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

- Forwarding companies willing to reduce the environmental impact of their shipments;
- Carriers and logistic providers being confronted with growing requests from customers as well as legislation to show their carbon footprint and improve their logistical chains from an environmental perspective;
- Political decision makers, consumers and non-governmental organisations which are interested in a thorough environmental comparison of logistic concepts including all transport modes (lorry, railway, ship, airplane and combined transport).

The environmental parameters covered are energy consumption, carbon dioxide (CO2), sum of all greenhouse gases (measured as CO2 equivalents) and air pollutants, such as

nitrogen oxides (NOx), sulphur dioxide (SO2), non-methane hydrocarbons (NMHC) and particulate matter (PM).

The online application offers two levels: In a "standard" input mode it allows a rough estimate. This can be refined in an "extended" input mode according to the degree of information available for the shipment. Thus, all relevant parameters like route characteristics and distance, load factor and empty trips, vehicle size and engine type are individually taken into account and can be changed by the user.

The initial version of EcoTransIT was published in 2003 with a regional scope limited to Europe. The version published in 2010 was expanded to a global scope. For the first time, EcoTransIT World (ETW) 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 (in particular 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 also taken into account.

Thus, ETW offers a 'best-practice' standard of carbon foot-printing and green accounting to the whole sector – compliant with international standards like the European standard EN 16258*.

The internet version of ETW as well as the integrated route planner for all transport modes has been realized by IVE Hannover. The methodology, input data and default values for the ecological assessments of the transport chains are developed and provided by ifeu Heidelberg, INFRAS Berne and Fraunhofer IML Dortmund. ifeu, INFRAS and Fraunhofer IML ensure that the ETW methodology is always up-to-date and in accordance with the international standards.

The present report "Methodology and Data Update" documents the methodology and the data currently embedded in ETW.

1.2 Accordance with EN 16258

Please consider that the following chapter is outdated due to the change from EN 16258 to ISO 14083. Currently the calculation of EcoTransIT World is not EN 16258 compliant, because the new conversion factors from the ISO 14083 are applied (and not the factors from the annex A).

Since the very first beginning EcoTransIT World has been provided a harmonized, independent methodology for the calculation of GHG emissions and air pollutants. The overall methodology and the approaches for each transport mode were very similar to the suggestion from the new European standard EN 16258 - which was published by the British Standards Institution (BSI) as BS EN 16258, by the German Institute for Standardisation (Deutsches Institut für Normung, DIN) as DIN EN 16258 and by Association française de normalisation (AFNOR) as NF EN 16258 at the end of 2012. Thus, the adaptation of the ETW methodology to the requirements of the European standard was feasible. The calculation of energy consumption and greenhouse gas (GHG) emissions (as CO₂ equivalents) by ETW is fully in accordance with EN 16258.

One methodological principle of the new standard is that in a first step the final energy consumption (litre Diesel, kWh electricity) of each part of the transport services (so-called leg) have to be calculated and in a second step these values have to be transferred into standardized energy consumption (MJ) and CO₂ equivalent emissions (kg CO₂e) on a Tank-to-Wheels (TTW) and Well-to-Wheels (WTW) basis (see chapter 3.3). The new standard contains the necessary conversion factors respectively default values for these calculations (e.g. MJ/litre or kg CO₂e/litre diesel). ETW uses the conversion factors for fuels included in EN 16258 without changes. For electricity the standard EN 16258 does not contain conversion factors as these are dependent on the mix of the generating plants which produced the electricity. The European standard only includes general rules for calculation of conversion factors for electricity. ETW uses own calculated conversion factors for electricity for trains which are in line with these general requirements of EN 16258.

In accordance with EN 16258 the final energy consumptions, the load factor or share of empty trips for the transport service can be measured or calculated by using default values. In general, ETW uses only default values for the calculation of energy consumption and GHG emissions since measured values can only be provided by the users themselves. The default values used by ETW are based on well-established data bases, statistical data and literature reviews. The data sources for default values suggested by EN 16258 were

considered. Therefore, ETW uses only default values being in accordance with new European Standard.

Furthermore, ETW allows users to change vehicle sizes, emission standards, load factors and shares of empty trips based on own data or measurements. In these cases, the user of ETW has to be ensured that the used figures are in accordance with the European standard. Fuel consumption figures as well as conversion factors can't be changed by the user. Fuel consumption data can only be replaced by business solutions of ETW after evaluation by the scientific partners if eu or INFRAS (see chapter 2).

In normal cases the goods considered with ETW do not fit exactly with the capacity of the chosen vehicles, trains, vessels or airplanes so that the energy consumption or emissions have to be allocated to the transport service considered. The European standard recommends carrying out the allocation using the product of weight and distance (e.g. tonne kilometres). Where this is not possible, then other physical units (e.g. pallet spaces, loading meters, number of container spaces) can be used instead of weight. ETW always uses the allocation unit tonne kilometres. Only for transport of containers the allocation unit TEU kilometres (= twenty-foot equivalent unit) is considered. The allocation methodologies used by ETW are also in accordance with the European standard.

Furthermore, the European standard describes requirements for the declaration of the results of the calculation: the declaration must disclose the well-to-wheels energy consumption and greenhouse gas emissions as well as the tank-to-wheels energy consumption and greenhouse gas emissions for the transport service considered. In addition, the sources used for the distance, load utilisation, empty trip percentage and energy consumption parameters must be identified. This report documents the default values used for the calculations in ETW and delivers additional information for declarations in accordance with EN 16258. Since the report is comprehensive and detailed, ETW provides a short declaration which includes all important information required (e.g. data sources used). The short declaration is provided by the ETW internet tool for each calculation carried out by the user.

Thus, the results for energy consumption and GHG emissions calculated with ETW are in compliance with the standard EN 16258*:2012.

Moreover, the European standard points out the following points, if the user wants to compare results calculated with different tools: "Please consult this standard to get further information about processes not taken into account, guidelines and general principles. If you wish to make comparisons between these results and other results calculated in accordance with this standard, please take particular care to review the detailed methods used, especially allocation methods and data sources.

"Last but not least" it has to be mentioned that one of the triggers for the European standard was that France planned to legalize oblige transport operators to show their customers the CO2 emissions produced by the transport service. However, it was not clear which methods should be used for determining the emissions. For this reason, in 2008 France made a standardisation application to the European Committee for Standardisation (CEN).

In the interim the French Decree No. 2011-1336 on "Information on the quantity of carbon dioxide emitted during transport" was published and updated in 2017. It stipulates that, by 1st of October 2013 at the latest, CO2e values of commercial passenger and freight transport which begin or end in France must be declared to the customer. This decree basically uses the same methodology as the European standard. However, there are also significant differences from the standard EN 16258. Furthermore, the French decree use different conversion factors compared to the EN 16258. They are not comparable so it is not possible to use the conversion factors of the European standard and the French decree at the same time. The ETW internet tool provides only results based on the conversion factors based on EN 16258. But in ETW business solutions the conversion factors included in the French decree can also be used so that ETW can also provide results in accordance with the French decree (see chapter 2).

1.3 Accredited to be compliant with the GLEC Framework

EcoTransIT World is the first emission calculation tool which is accredited to be compliant with the global GLEC framework. The Global Logistics Emissions Council (GLEC) framework established by Smart Freight Centre (SFC) has been created to be the leading methodology for freight transports and logistics operations. It allows companies to consistently calculate their GHG footprint across the global multi-modal supply chain.

As part of the accreditation statement SFC confirmed the ETW calculation to be in line with Well-to-Wheel GHG emissions according the scopes of the GHG Protocol Corporate Value Chain Accounting and Reporting Standard.



ACCREDITATION STATEMENT

IVE mbH: EcoTransIT World

- Calculation scope: well-to-wheel GHG emissions, expressed in units of CO₂ equivalent according to the scopes of the GHG Protocol Corporate Value Chain Accounting and Reporting Standard
 Input data Yspes: Modelled, Primary (Disaggregated) for Road
 Modal coverage: Road, Rai, Ari, Inland Waterways, Sea, Logistics Sites
 Geographic coverage: Global

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ETW business solutions 7

The ETW Business Solutions contain standardised interfaces (API) for automatic emission calculation of huge amounts of transport chains. Already today, several hundred million transports are calculated every year via the API. The use ranges from an individualised website to semi-automatic calculations of transport lists in CSV format to a fully automatic solution based on a SOAP XML Webservice (WSDL).

The ready-to-use standard solutions are extremely flexible and allow to calculate complex intermodal transport chains with little or much customer-specific transport information. If necessary, user-defined adaptations or extensions to the software are made available.

The interfaces are offered as Software-as-a-Service. The associated servers are provided by IVE mbH and are continuously monitored by specific monitoring software. Server costs and regular updates are included in the license fees. In addition to the API, the IVE mbH team offers to calculate, analyse and present customer-specific transports as consultation projects.

2.1 Additional features compared to the website http://ecotransit.org

The ETW Business Solution enables valuable additional features which are not available on the global website of ETW. These features are:

- Automated calculation of large transport volumes
- Individual technical and methodical consultation
- Consideration of customer-specific transport characteristics
- Calculation of container sea shipments via the Clean Cargo methodology, including
 - o calculation of EC, GHG emissions and SOx based on CCWG trade lane emission factors
 - o adjustable allocation factor (default 70%) and flexible distance correction factor (default 15%)
 - sophisticated trade lane mapping
 - usage of SCAC based emission factors (only for CCWG members)
- Automatically flight number analyses via OAG.com interface:



enables appliance of an aircraft share via flight Absolute Aviation Advantage



number, flight carrier or airport pair (inclusive belly or freighter detection)

- optional stop-over identification
- Additional vehicle classes, like over 250 different plane types or additional truck and train classes
- Calculation of logistics sites emissions for e.g. warehouse or transhipment processes via the REff Tool® (https://reff.iml.fraunhofer.de/) and REff Tool Fraunhofer IML's methodology¹
- Calculation with Twenty-foot Equivalent (TEU) and Forty-foot Equivalent (FEU) containers
- Automatically conversion of the truck load to the respective load factor (FTL, LTL, FCL) including the usage of the respective vehicle type
- Consideration of individual transport distances per leg for all transport types
- Output split per country or vehicle type (can be used e.g. for result manipulation forward to the French decree)
- LocationEditor: Inclusion and correction of new or customer-specific locations
- LogViewer: Create statistics and analyses of the calculated results
- Data security provided by dedicated hardware with secured encrypted data transfer
- Participating within the EWI to initiate new working groups, methodology issues and help to steer ETW

All features can be adjusted or enlarged on individual basis towards to the company own needs.

2.1.1 Methodology support included

All ETW Business Solutions include a consulting package which automatically enables methodology support done by our scientific partners.

¹ The ETW Business Solutions provides the possibility of assessing the environmental impact of logistics sites' operations on the basis of company's real data. Logistics sites play a connecting role within transport chains and refer to all sites that combine different transport legs (within and between modes) or are the starting or end point of transport chains. The assessment scope follows the methodology as described in /Fraunhofer IML 2019/.

In principle almost, every development/ adjustment to the customers' needs can be done within the ETW Business Solutions. The effort for such an individual solution depends on the respective specification.

Available Interfaces (API) 2.2

The ETW Business Solutions contain standardised interfaces (API) for automatic mission calculation of huge amounts of transport chains. Already today, several hundred million transports are calculated every year via the API. The use ranges from an individualised website to semi-automatic calculations of transport lists in CSV format to a fully automatic solution based on a Soap XML Web Service (WSDL). The ready-to-use standard solutions are extremely flexible and allow to calculate complex intermodal transport chains with little or much customer-specific transport information. If necessary, user-defined adaptations or extensions to the software are made available.

The interfaces are offered as Software-as-a-Service. The associated servers are provided by IVE mbH and are continuously monitored by specific monitoring software. Server costs and regular updates are included in the license fees.

Figure 1 Different kinds of standardized interfaces



2.2.1 SOAP XML Webservice

The SOAP XML Webservice enables the calculation of single requests on the base of a WSDL web service. The request can include all modes including an unlimited amount of via points on base of the ETW characteristics. The SOAP XML webservice includes several request types, like calculation requests, flight number requests, location and vehicle requests and many more. Due to these request types, it is possible to create a complete external calculation website which uses only SOAP XML requests/ responses.

2.2.2 CSV File Mass Calculation

Within the interface of the CSV File Mass Calculation the user can upload request files including huge numbers of transport services and download response files (csv, pdf, kml or rtf) including calculation results. Within the so-called mass calculation every transport service will be calculated separately. The upload and download can be done via a login and password secured website or via a sFTP interface.

2.2.3 ETW on Customer Website

ETW can be included on customers' websites. The integration can be realized via a so called iframe or by the customer IT itself by using the SOAP XML Webservice.

Calculation Service 2.3

In addition to the API, the IVE mbH team offers to calculate, analyse and present customerspecific transports as consultation projects. Already now several shipper companies using this service of IVE to calculate their shipments on detailed level.

3 System boundaries and basic definitions

The following subchapters give an overview about the system boundaries and definitions used in ETW. In comparison to the European standard EN 16258 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services" ETW allows also the quantification of other emissions like air pollutants for transport chains. Nevertheless, ETW considers all requirements of EN 16258 independent of the environmental impact category considered. The system boundaries as well as definitions are chosen in such a way that they are in accordance with the new European standard.

Transport service and vehicle operation system 3.1

ETW allows the calculation of different environmental impact categories (see next subchapter) for a single transport from A to B or for complex transport chains using different transport modes. In the context of the European standard EN 16258 these transport cases are called transport services. According to EN 16258 a transport service is a "service provided to a beneficiary for the transport of a cargo [...] from a departure point to a destination point". The EN 16258 methodology requires that the transport service has to be broken down into sections in which the cargo considered travels on a specified vehicle, i.e. without changing vehicle. This section of route is also called leg in the standard. The level of energy consumption and emissions for the consignment under consideration must be determined for each leg and then added to give an overall result. ETW works exactly in this way. For each leg the quantification is done separately and the overall sum is calculated for the entire transport service. Therefore, ETW fulfils these requirements of EN 16258.

Additionally, EN 16258 demands that energy consumption and the GHG emissions for each leg have to be quantified using the so-called Vehicle Operation System (VOS). VOS is the term which the standard uses to denote the round-trip of a vehicle in which the item in question is transported for a section of the route. The VOS does not necessarily have to be an actual vehicle round-trip. It can also consist of all vehicle round-trips for one type of vehicle or of one route or leg or even of all vehicle round-trips in a network in which the transport section in question lies or would lie (for future transport services). In the end the energy consumption for the entire VOS needs to be determined and then allocated to the transport leg and the individual consignment under consideration.

In accordance with EN 16258 the energy consumption of a VOS can be measured or be calculated by using default values. As mentioned in chapter 1.2 the internet tool of ETW only uses default values particularly for energy consumption of trucks, trains, ships and airplanes. Therefore, the VOS established for the calculation for ETW is the entire round trip of these vehicles or vessels. To consider the energy consumption for a single transport service the fuel or electricity consumption of the vehicles or vessels are allocated to the shipment by using the units' tonne kilometres or TEU kilometres. The transport distance is calculated by the integrated route planner of ETW (see chapter 5). The weight of the shipment or the number of TEU is calculated by using the maximum payload capacity, the load factor and share of additional empty trips (see chapter 4.2). Similar to energy consumption ETW considers the load factor and additional share of empty trips for the entire VOS. Thus, the ETW definition of VOS fulfils all requirements of the EN 16258. However, it must be noted that specific energy consumption values per tonne kilometre or TEU kilometre used in ETW already take account of the load factors and empty trips and link the energy consumption calculation directly to the allocation step - so, instead of two separate steps mentioned in the EN 16258 (calculation of energy consumption and afterwards allocation to the single shipment), ETW combine both steps. But the results are identical independent of combining the two steps or not.

3.2 **Environmental impacts**

Transportation has various impacts on the environment. These have been primarily analysed by means of life cycle analysis (LCA). An extensive investigation of all kinds of environmental impacts has been outlined in /Borken 1999/. The following categories were determined:

- Resource consumption
- Land use
- Greenhouse effect
- Depletion of the ozone layer
- Acidification
- Eutrophication
- Eco-toxicity (toxic effects on ecosystems)
- Human toxicity (toxic effects on humans)
- Summer smog
- Noise

The transportation of freight has impacts within all these categories. However, only for some of these categories it is possible to make a comparison of individual transport services on a quantitative basis. Therefore, in ETW the selection of environmental performance values had to be limited to a few but important parameters. The selection was made according to the 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.

The following parameters for environmental impacts of transports were selected:

Table 1 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
CO₂e	Greenhouse gas emissions as CO ₂ -equivalent. CO ₂ e is calculated as follows (mass weighted): CO ₂ e = CO ₂ + 25 * CH ₄ + 298 * N ₂ O CH ₄ : Methane N ₂ O: Nitrous Oxide	Greenhouse effect
NOx	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
SO ₂	Sulphur dioxide emissions	Acidification, eco-toxicity, human toxicity
NMHC	Non-methane hydro carbons	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

Thus, the categories land use, noise and depletion of the ozone layer were not taken into consideration. In reference to electricity-driven rail transport, the risks of nuclear power generation from radiation and waste disposal were also not considered. PM **emissions** are defined as exhaust emissions from combustion; therefore, PM emissions from abrasion and twirling are also not included in ETW.

In accordance with EN 16258 and the ISO 14083 energy consumption and GHG emissions measured as CO₂ equivalents can be calculated with ETW. The definitions used by ETW are similar to the definitions of EN 16258 and the ISO 14083.

3.3 System boundaries of processes

In ETW, only environmental impacts linked to the operation of vehicles and to fuel or energy production are considered. Therefore, the following are not included:

- The production and maintenance of vehicles;
- The construction and maintenance of transport infrastructure;
- Additional resource consumption like administration buildings, stations, airports, etc...

All emissions directly caused by the operation of vehicles and the final energy consumption are taken into account. Additionally, all emissions and the energy consumption of the generation of final energy (fuels electricity) are included. The following figure shows an overview of the system boundaries.

Figure 2 System boundaries of processes /own figure adapted from Geodis/



In ETW, two process steps and the sum of both are distinguished:

- Final energy consumption and vehicle emissions (= operation; Tank-to-Wheels TTW),
- Upstream energy consumption and upstream emissions (= energy provision, production and distribution; Well-to-Tank WTT),
- Total energy consumption and total emissions: Sum of operation and upstream figures (Well-to-Wheels WTW).

The European standard EN 16258 requires the calculation and declaration of energy consumption and GHG emissions of transport services on TTW as well as WTW basis. ETW provides both figures for energy consumption and GHG emissions. In this context attention should be paid to fact that WTW energy consumption is also very often referred to as primary energy consumption, TTW energy consumption as final energy consumption.

3.3.1 Environmental relevance of excluded processes

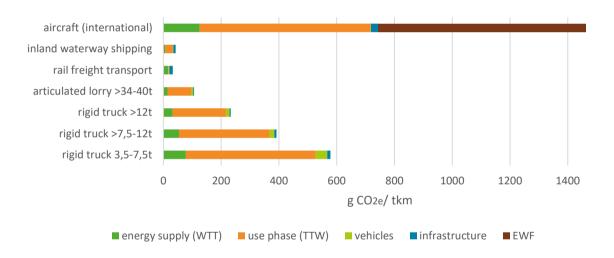
The EN 16258 follows a Well-to- wheels approach and thus does not include the transport infrastructure (streets, railways...) and the vehicles used for transport (e.g. manufacturing, maintenance and end-of-life for trucks, airplanes, trains and ships).

In this chapter a short information on the relevance for these processes for the entire process chain is given.

A recently published study for the Umweltbundesamt (ifeu/infras/Öko Institut 2020) shows that the relevance of the vehicle and the infrastructure differs between the different 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 emissions. For the GHG emissions, the infrastructure contributes only marginally to the overall impacts. Vehicles are also almost irrelevant for air, train or ship 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 3 Comparison of the GHG emissions from road transportation in Germany in 2017 in g per tkm [ifeu/ infras/ Öko Institut 2020]



^{*}Vehicles includes production, maintenance and end-of-life

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 are driven using 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

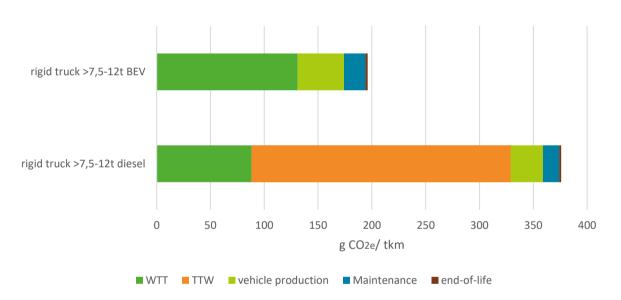
^{**} For aircrafts, the additional climate impacts of emissions at high altitudes are included by using an emission weighting factor (EWF). More details on these effects can be found in chapter 6.5.3.

trucks have no direct 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 [Ricardo, ifeu, e4tech 2020] concludes that the battery manufacturing of lithium ion batteries today lead 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 GVW has almost half the GHG emissions compared to a diesel truck.

Figure 4 Comparison of the GHG emissions for a 12 t GVW truck in 2020 with EU electricity mix [Ricardo, ifeu, e4tech 2020]



This assessment shows that even though the emissions from vehicle manufacturing are increasing for alternatively fueled vehicles, GHG emissions are still dominated by the WTW part of the process chain.

3.4 Transport modes and propulsion systems

Transportation of freight is performed by different transport modes. Within ETW, the most important modes using common vehicle types and propulsion systems are considered. They are listed in the following table.

Transport mode	Vehicles/Vessels	Propulsion energy		
Road	Road transport with single trucks and truck trailers/articulated trucks (different types)	Diesel fuel, CNG, LNG, Electricity		
Rail	Rail transport with trains of different total gross tonne weight	Electricity and diesel fuel		
Inland waterways	Inland ships (different types)	Diesel fuel		
Sea	Ocean-going sea ships (different types) and ferries	Heavy fuel oil (HFO) / marine diesel oil (MDO) / marine gas oil (MGO)		
Aircraft transport	Air planes (different types)	Kerosene		

Table 2 Transport modes, vehicles and propulsion systems

Spatial differentiation 3.5

In ETW worldwide transports are considered. Therefore, environmental impacts of transport can vary from country to country due to country-specific regulations, energy conversion systems (e.g. energy carrier for electricity production), traffic infrastructure (e.g. share of motorways and electric rail tracks) and topography.

Special conditions are also relevant for international transports by sea ships. Therefore, a spatial differentiation is necessary. For sea transport, a distinction is made for different trade lanes and areas (Sulphur Emission Control Areas/SECA). On the contrary, for aircraft transport, the conditions relevant for the environmental impact assessments are similar all over the world.

3.5.1 Road and rail

For road and rail transport, ETW distinguishes between Europe and other countries. In this version of ETW, it was not possible to find accurate values for the transport systems of each country worldwide. For this reason, we defined seven world regions and within each region, we identified the most important countries with high transport performance and considered each one individually. For all other countries within a region, we defined default values, normally derived from an important country of this region. In further versions, the differentiation can be refined without changing the basic structure of the model. The following table shows the regions and countries used.

Table 3 Differentiation of	of regions and countries for road and rail transport
----------------------------	--

ID	Region	Country	Code	ID	Region	Country	Code
101	Africa	default	afr	514	Europe	Iceland	IS
102	Africa	South Africa	ZA	515	Europe	Ireland	IE
201	Asia and Pacific	default	asp	516	Europe	Israel	IL
202	Asia and Pacific	China	CN	517	Europe	Italy	IT
203	Asia and Pacific	Hong Kong	HK	518	Europe	Latvia	LV
204	Asia and Pacific	India	IN	519	Europe	Lithuania	LT
205	Asia and Pacific	Japan	JP	520	Europe	Luxembourg	LU
206	Asia and Pacific	South Korea	KR	521	Europe	Malta	MT
301	Australia	default	aus	522	Europe	Netherlands	NL
302	Australia	Australia	AU	523	Europe	Norway	NO
401	Central and South America	default	csa	524	Europe	Poland	PL
402	Central and South America	Brazil	BR	525	Europe	Portugal	PT
501	Europe	default	eur	526	Europe	Romania	RO
502	Europe	Austria	AT	527	Europe	Slovakia	SK
503	Europe	Belgium	BE	528	Europe	Slovenia	SI
504	Europe	Bulgaria	BG	529	Europe	Spain	ES
505	Europe	Cyprus	CY	530	Europe	Sweden	SE
506	Europe	Czech Republic	CZ	531	Europe	Switzerland	CH
507	Europe	Denmark	DK	532	Europe	Turkey	TR
508	Europe	Estonia	EE	533	Europe	United Kingdom	GB
509	Europe	Finland	FI	601	North America	default	nam
510	Europe	France	FR	602	North America	United States	US
511	Europe	Germany	DE	701	Russia and FSU	default	rfs
512	Europe	Greece	GR	702	Russia and FSU	Russian Federation	RU
513	Europe	Hungary	HU		-		

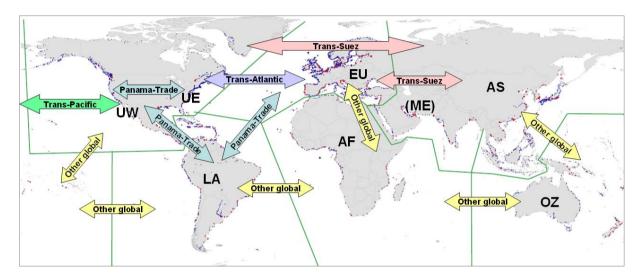
Significant influencing factors are the types of vehicles used, the type of energy, the share of biofuel blends and the conversion factors used. Wide variations result particularly from the national mix of electricity production.

Differences may exist for railway transport, where the various railway companies employ different locomotives and train configurations. However, the observed differences in the average energy consumption are not significant enough to be established statistically with certainty. Furthermore, within the scope of ETW, it was not possible to determine specific values for railway transport for each country. Therefore, a country specific differentiation of the specific energy consumption of cargo trains was not carried out.

3.5.2 Sea and inland ship

For ocean-going vessels, a different approach was taken because of the international nature of their activity. The emissions for sea ships were derived from the Fourth IMO Greenhouse Gas Study /IMO 2020/. For each trade lane, the size distribution of deployed ships is regularly analysed, using schedules from ocean carriers and extracts of the data collected by container carriers under the framework of the Clean Cargo Working Group (CCWG). Ship size restrictions on certain trade lanes (e.g. Suez or Panama canal) were also considered (see also Chapter 6.3). The trade lane-specific emission factors were aggregated from IMO ship types and size classes using the trade lane-specific vessel sizes. Figure 3 shows the connected world regions and the definition of ETW marine trade lanes. The regions considered include UW - North America / West coast, UE - North America / East Coast, LA – South America, EU – Europe, AF – Africa, AS – Asia and OZ – Oceania.

Figure 5: ETW division of the world oceans and definition of major trade lanes.



For inland ships, three ship types are differentiated that are used by default on a given CEMT river class /CEMT 1992/. European rivers are categorized in three size classes (CEMT classes I-IV, class V, and class VI and above) and vessels are allocated to classes according to their ability to navigate specific rivers. For waterways outside Europe, the CEMT classification is not available. Class V is therefore used per default outside Europe.

Overview of country and mode specific parameters

The following table summarizes all countries/regions and mode-specific parameter. For aircraft only, mode specific parameters are considered.

Table 4 Parameter characterisation

	Country/region specific parameter	Mode specific parameter		
Road	Fuel specifications: - Sulphur content - Share biofuels Emission regulation Topography Available vehicles Default vehicles for long-distance/feeder	Truck types: - Final energy consumption - Emission factors (TTW): NOx, NMHC, PM		
Rail	Fuel specifications: - Sulphur content - Share biofuels Energy and emission factors of upstream process Topography type depending energy consumption Available train types Default vehicles for long-distance/feeder Diesel tracks	Train type, weight and energy type: Final energy consumption (functions) Emission factors for diesel traction (TTW): NOx, NMHC, PM		
Inland Ship	Fuel specifications: - Sulphur content - Share biofuels CEMT waterway class determines: - default ship type and thus emission factors in port and on-river - Optional ship types depending on waterway capacity Origin/destination determines default emission standard in Standard input mode	Ship type Cargo type (container/bulk) Emission standard Final energy consumption Emission factors (TTW) NOx, NMHC, PM		
Sea Ship	Origin and destination determine the route and thus: Distance within/outside Emission Control Area (ECA) determines fuel type (HFO/MDO) and respective set of emission factors at sea Origin/destination port location (within ECA, or subject to other regulation/incentive) determines fuel type (HFO/MDO) and respective set of emission factors in port Choice of trade lane determines aggregated emission factors at sea (based on the distribution of ship sizes on the respective trade lane)	Chosen vessel type (liquid/dry bulk, container, general cargo, RoRo) and size class, determines emission factors at sea Speed adjustment option Final energy consumption (TTW) Emission factors (TTW): NOx, NMHC, PM		
Aircraft		Aircraft type: - Final energy consumption (TTW) - Emission factors (TTW): NOx, NMHC, PM - Design range		
	Fuel depend			
All Modes	Energy conversion factors (WTT and TTW) from ISO 14083 CO2e-conversion factors (WTT and TTW) from ISO 14083 CO2-conversion factors (WTT and TTW) compatible with ISO 14083 Upstream emission factors (WTT) for fuels see chapter 6.6.1: NOx, NMHC, PM Upstream energy and emission factors (WTT) for electricity production from national electricity production mixes (see chapter 6.6.2): CO ₂ , CO ₂ e, NOx, NMHC, PM			

Basic definitions and calculation rules 4

This chapter gives an overview of basic definitions, assumptions and calculation rules for freight transport used in ETW. The focus will be on the common rules for all transport modes and the basic differences between them. Detailed data and special rules for each transport mode are described in chapter 6. In general, the calculation rules and methodologies used by ETW are in accordance with the European standard EN 16258*.

Main factors of influence on energy and emissions of 4.1 freight transport

The energy consumption and emissions of freight transport depends on various factors. Each transport mode has special properties and physical conditions. The following aspects are of general importance for all modes of transport:

- Vehicle/vessel type (e.g. ship type, freight or passenger aircraft), size and weight, payload capacity, motor concept, energy, transmission,
- Capacity utilisation (load factor, empty trips),
- Cargo specification (mass limited, volume-limited, general cargo, pallets, container),
- Driving conditions: number of stops, speed, acceleration, air/water resistance,
- Traffic route: road category, rail or waterway class, curves, gradient, flight distance,
- Total weight of freight and
- Transport distance.

In ETW, parameters with high influence on energy consumption and emissions can be changed in the extended input mode by the user. Some other parameters (particularly the transport distance) are selected by the routing system. All other parameters, which are either less important or cannot be quantified easily (e.g. weather conditions, traffic density and traffic jam, number of stops) are included in the average environmental key figures. The following table gives an overview on the relevant parameters and their handling (standard input mode, extended input mode, routing).

Independent of the possibility that user can change values ETW includes so called standard values or default values for all parameters. The default values used by ETW will be presented in the next chapters. All default values are chosen in such a way, that they are in line with the European standard EN 16258*. Or in other words: If users calculate energy consumption and CO2e emissions based on default values included in ETW the results fulfil always the requirements of EN 16258*.

Table 5 Classification and mode (standard, extended, routing) of main influence factors on energy consumption and emissions in ETW

Sector	Parameter	Road	Rail	Sea ship	Inland Ship	Aircraft
Vehicle,	Type, size, payload capacity	E	Е	Е	E	E
Vessel	Drive, energy	Е	Е	Α	Α	Α
	Technical and emission standard	ш	E	Α	E	A
Traffic route	Road category, waterway class	R			R	
	Gradient, water/wind resistance	Α	Α	Α	Α	Α
Driving	Speed	Α	Α	E	Α	Α
Conditions	No. of stops, acceleration	Α	Α	Α	Α	Α
	Length of LTO/cruise cycle					R
Transport	Load factor	Е	Е	Е	Е	E
Logistic	Empty trips	Е	Е	Е	Е	E
	Cargo specification	S	S	S	S	S
	Intermodal transfer	Е	Е	Е	Е	E
	Trade-lane specific vessels			R		
Transport	Cargo mass	S	S	S	S	S
Work	Distance travelled	R	R	R	R	R

Remarks:

4.2 Logistics parameters

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 transport and the vehicles/vessels used for the transport. Therefore, ETW gives the possibility to adjust these figures in the extended input mode 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

A = included in average figures,

S = selection of different categories or values possible in the standard input mode,

E = selection of different categories or values possible in the extended input mode.

R = selection by routing algorithm.

empty = not relevant

kg/m³ and below /Van de Reyd and Wouters 2005/. 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 has to be transported and more energy will be consumed. At the same time, higher cargo weights on trucks and rail lead to increased fuel consumption.

Marine container vessels behave slightly differently with regard to 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. The emissions of container vessels are calculated on the basis of transported containers, expressed in twenty-foot equivalent units (TEU). 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.

4.2.1 Definition of payload capacity

In ETW payload capacity is defined as mass related parameter.

Payload capacity [tonnes] = maximum mass of freight allowed

For marine container vessels capacity is defined as number of TEU:

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

This definition is used in the calculation procedure in ETW, however it is not visible because the TEU-based results are converted into tonnes of freight (see also chapter 4.2.2):

Conditions for the determination of payload capacity are different for each transport mode, as explained in the following clauses:

Truck

The payload capacity of a truck is limited by the maximum vehicle weight allowed. Thus, the payload capacity is the difference between maximum vehicle weight allowed and empty weight of vehicle (including equipment, fuel, driver, etc.). In ETW, trucks are defined for five total weight classes. For each class an average value for empty weight and payload capacity is defined.

Train

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 has to 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 influence factor for energy consumption and emissions is the relationship between payload and total weight of the wagon (see chapter 4.2.2). In ETW a typical average wagon is defined based on wagon class UIC 571-2 (ordinary class, four axles, type 1, short, empty weight 23 tonnes, /Carstens 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 ETW 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 2012, SNCF Geodis 2012/. In ETW average values for these special wagon types are used.

All values for empty weight and payload capacity of wagon types used in ETW are given in Table 7.

Ocean going vessels and inland vessels

The payload capacity for bulk, general cargo and other non-container vessels is expressed in dead weight tonnage (DWT). Dead weight tonnage (DWT) is the measurement of the vessel's carrying capacity. The 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. Different DWT values are based on different draught definitions of a ship. The most commonly used and usually chosen if nothing else is indicated is the DWT at scantling draught of a vessel, which represents the summer freeboard draught for seawater /MAN 2006/, which is chosen for ETW. For container vessels the DWT is converted to the carrying capacities of container-units, expressed as twenty-foot equivalent (TEU).

Aircraft

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 aircrafts (including kerosene). Typical payload capacities of freighters are approximately from 13 tonnes (for small aircrafts) up to 130 tonnes (for large aircrafts). 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 (for medium aircrafts) and 23 tonnes (for large aircrafts such as the Boeing 777). Small passenger aircrafts have partially only a payload capacity for belly freight of 100 kg. For more details, see chapter 6.5.

Freight in Container

ETW allows the calculation of energy consumption and emissions for container transport in the extended input mode. Emissions of container vessels are calculated on the basis of the number of containers-spaces occupied on the vessel, expressed in "Number of TEUs" (Twenty Foot Equivalent Unit). To achieve compatibility with the other modes, the netweight of the cargo in containers is considered as capacity utilisation of containerized transport (see 4.2.2).

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. The following table provides the basic dimensions for the 20' and 40' ISO containers.

Table 6: Dimensions of the standard 20' and 40' container.

	L*W*H [m]	Volume [m³]	Empty weight	Payload capacity	Total weight		
20' = 1 TEU	6.058*2.438*2.591	33.2	2,250 kg	21,750 kg	24,000 kg		
40' = 2 TEU	12.192*2.438*2.591	67.7	3,780 kg	26,700 kg	30,480 kg		
Source: GDV 2010							

The empty weight per TEU is for an average closed steel container between 1.89 t (40' container) and 2.25 t (20' container). The maximum payload lies between 13.35 t per TEU (40' container) and 21.75 t per TEU (20' container). Special containers, for example for carrying liquids or open containers may differ from those standard weights.

Payload capacity for selected vehicles and vessels

In the extended input mode, a particular vehicle and vessel size class and type may be chosen. For land-based transports the size classes are based on commonly used vehicles. For air transport the payload capacity depends on type of chosen aircraft. For marine vessels the size classes were chosen according to common definitions for bulk carriers (e.g. Handysize). For a better understanding, container vessels were also labelled e.g. "handysize-like."

The following table shows key figures for empty weight, payload and TEU capacity of different vessel types used in ETW. For marine vessels, it lists the vessel types and classes as well as the range of empty weight, maximum DWT and container capacities of those classes. The emission factors were developed by building weighted averages from the list of individual sample vessels. Inland vessel emission factors were built by aggregating the size of ships typically found on rivers of class IV to VI.

Table 7 Empty weight and payload capacity of selected transport vessels

Vehicle/ vessel	Vehicle/vessel type	Empty weight [tonnes]	Payload capacity [tonnes]	Vessel capacity [TEU or vessel]	Max. total weight [tonnes]
Truck	<=7.5 tonnes	4	3.5	-	7.5
	>7.5-12 tonnes (D/E)	6/6.5	6/5.5	-	12
	>-12-20 tonnes (D/E)	9/10.7	11/9.3	-	20
	>20-26 tonnes	11	15	1	26
	>26-40 tonnes (D/E)	14/17.5	26/22.5	2	40
	>40-50 tonnes	15	35	2	50
	>50-60 tonnes	20	40	2	60
	>60 tonnes	25	65	2	90
Train	Standard wagon *	23	61	-	84
	Car wagon **	28	21 (10 cars)	-	59
	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
Sea Ship	General cargo	<850	<5,000	<300	
	Feeder ***	840-3,090	5000-14,999	300-999	
	Handysize-like ***	2,500-7,200	15,000-34,999	1,000-1,999	
	Handymax-like ***	5,800-12,400	35,000-59,999	2,000-3,499	
	Panamax-like ***	10,000-16,500	60,000-79,999	3,500-4,699	
	Aframax-like ***	13,300-24,700	80,000-119,999	4,700-6,999	
	Suezmax-like ***	20,000-41,200	120,000-199,999	>7,000	
	VLCC (liquid bulk only)	33,300-53,300	200,000-319,999		
	ULCC (liquid bulk only)	53,300-91,700	320,000-550,000		
Inland	Neo K (class IV) N/A in ETW	110	650		
Ship	Europe-ship (class IV)	230	1,350		
	RoRo (class Va) N/A in ETW	420	2,500	200	
	Tankship (class Va)	500	3,000		
	JOWI ship (class VIa)	920	5,500		
	Push Convoy	1,500	9,000		
Aircraft	Boeing 737-300SF	43.6	19.7	-	63.3
(only	Boeing 767-300F	86.5	53.7	-	140.2
Freighter)	Boeing 747-400F	164.1	113.0	-	276.7
	Boeing 777-200F	156.2	102.9		347.5
	Airbus A330-200F	109.0	65.0		233.0

Remarks: D/E: Values for Diesel and CNG / Electric; Max. total weight for Ship = DWT (Dead Weight Tonnage), for Aircraft: Empty weight includes fuel; Max. total weight = Take-off weight.

^{*}type specific values, used for general train type

^{**}average values from transport statistics

^{***}Seagoing vessels are either bulk carriers with payload capacity in tonnes or container vessels with payload capacity in TEU. The nomenclature such as "Handysize" is usually only used for bulk carriers

4.2.2 Definition of capacity utilisation

In ETW the capacity utilisation is defined as the ratio between freight mass transported (including empty trips) and payload capacity. Elements of the definition are:

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

For railway transport, there is often no statistically available figure for the load factor. Normally railway companies report net tonne kilometre and gross tonne kilometre. Thus, the ratio between net tonne kilometre and gross tonne kilometre is the key figure for the capacity utilisation of trains. In ETW, capacity utilisation is needed as an input. For energy and emission calculations, capacity utilisation is transformed to net-gross-relation according the following rules:

Abbr.	Definition	Unit
EW	Empty weight of wagon	[tonne]
CP	Payload capacity	[tonnes]
CU _{NC}	Capacity utilisation	[%]
Abbr.	Formula	
CU _{NG}	Net-gross relation = capacity utilisation / (capacity utilisation + empty wagon weight / mass capacity wagon).	[net tonnes/gross tonnes]
	CU _{NG} = CU _{NC} /(CU _{NC} + EW/CP)	

In ETW, empty wagon weight and payload capacity of rail wagons are defined for different wagon types. These values are used (see chapter 4.2.1, Table 7).

4.2.3 Capacity Utilisation for specific cargo types and transport modes

The former chapter described capacity utilisation as an important parameter for energy and emission calculations. But in reality, 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 has to be allocated to the transport is not clear or known
- Number of TEU is known but not the payload per TEU (or inverse)
- For this reason, in ETW three types of cargo are defined for selection, if no specific information about the capacity utilisation is known:
- 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 8 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

Remarks: Special transport examples, without empty trips Source: Mobilitäts-Bilanz /ifeu 1999/

The task now is to determine typical load factors and empty trip factors for the three categories (bulk, average, volume). This is easy for average goods, since in these cases values are available from various statistics. It is more difficult for bulk and volume goods:

Bulk (heavy): For bulk goods, at least with regard to the actual transport, a full load (in terms of weight) can be assumed. What is more difficult is assessing the lengths of the additionally required empty trips. 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 with regard to 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 to a large extent 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 vehiclekm for bulk and volume goods.

Capacity utilisation of containerized sea and intermodal transport: For containerized sea transport 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 the Clean Cargo Working Group (CCWG) the net weight of average goods is defined at 10.0 tonnes per TEU [CCWG 2014]. 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 9 provides the values used in ETW as well as the formula for calculating cargo loads in containers. For more details, see appendix chapter 7.1.

Table 9 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 2014; assumptions ETW.				

Capacity utilisation of road and rail transport for different cargo types

The average load factor in long distance road transport with heavy trucks was about 55 % in Germany in 2013 /KBA 2013 / and 58% in 2001 /KBA 2002 /. 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 (/Kessel und Partner 1998/).

The load factor for the "average cargo" of different railway companies are in a range of about 0.5 net-tonnes per gross-tonne /Railway companies 2002a/. For dedicated freight transports the value range between 0.3 and 0.66 net-tonnes per gross-tonne /DB Schenker 2012, SNCF Geodis 2012/. According to /Kessel und Partner 1998/ Deutsche Bahn AG (DB AG) the share of additional empty vehicle-km was 44 % in 1996. This can be explained by a high share of bulk commodities in railway transport and a relatively high share of specialized rail: cars. The share of additional empty trips for dedicated trains ranges from 20 % to 100 % (see Table 10).

ifeu calculations have been carried out for a specific train configuration, based on the assumption of an average load factor of 0.5 net-tonnes per gross tonne. It can be concluded that 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 for the loaded vehicle-km with bulk goods. Additional empty vehicle-km is estimated in the range of 60 % for road and 80 % for rail transport.
- The weight related load factor for the loaded vehicle-km with volume goods is estimated in the range of 30 % for road and rail transport. The empty trip factor is estimated to be 10 % for road transport and 20 % for rail transport.

These assumptions take into account the higher flexibility of road transport as well as the general suitability of the carrier for other goods on the return transport.

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

All assumptions and average values used in ETW as default are summarized in Table 10.

	Load factor LF _{NC}	Empty trip factor ET	Capacity utilisation CU _{NC}	Relation Nt/Gt CU _{NG}
Train wagon				
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 %	63 %	0,66
Truck			•	
Bulk	100%	60%	63%	
Average	60%	20%	50%	
Volume	30%	10%	27%	
Source: DB Cargo, SNCF	Geodis, ifeu est	imations	<u>.</u>	

Table 10 Capacity utilisation of road and rail transport for different types of cargo

Capacity utilisation for container transport on road and rail

ETW enables the possibility to define a value for t/TEU. At the website this value is active if a container transport (freight unit TEU) is selected. In this case the load factor for trucks and trains will be calculated automatically.

The corresponding formula for the truck is

LF_{Truck} = (Container_{brutto} * Container amount_{vehicle}) / payload capacity_{truck}

The gross weight of a container is the sum of net weight [t/TEU] and the container weight itself (compare Table 9). The maximum payload of a truck is declared within Table 7.

At trains the load factor will only be calculated for container trains. The corresponding formula for the trains is

LF_{Container Train} = (Container brutto * Container amount wagon) / payload capacity container wagon

The gross weight of a container is the sum of net weight [t/TEU] and the container weight itself (compare Table 9). The payload capacity [tonnes] of a container wagon is declared within Table 7. ^

Capacity utilisation of ocean-going vessels for different cargo types

Capacity utilisation for sea transport is differentiated per vessel type. Most significantly is the differentiation between bulk vessels and container vessels, which operate in scheduled services. The operational cycle of both transport services lead to specific vessel utilisation factors. Furthermore, the vessel load factor and the empty trip factor have been combined to the vessel capacity factor for reasons to avoid common mistakes. It is assumed that performance of ocean-going vessels sailing under laden conditions (when carrying cargo) and ballast conditions (when empty) are relatively similar. The cargo weight of ocean-going vessels only influences the energy consumption to a minor extend, in particular compared to other modes of transport. Reasons are the need to reach a certain draft for safety reasons, which is adjusted by taking up or discharging ballast water and the dominance of other factors that determine the vessels' fuel consumption, namely wave and wind resistance. Wave resistance exponentially increases with speed, which makes speed as one of the most important parameters. While for bulk carriers the difference between laden and ballast conditions might be recognisable, it should be acknowledged that container carriers carry cargo in all directions and always perform with both cargo and ballast water loaded. For container vessels the nominal TEU capacity (maximum number of TEU units on-board) is considered the full load.

The combined vessel utilisation for bulk and general cargo vessels is assumed to be between 48 % and 61 % and follows the IMO assumptions /IMO 2009/. Bulk cargo vessels usually operate in single trades, meaning from port to port. In broad terms, one leg is full whereas the following leg is empty in normal cases. However, cycles can be multi-angular and sometimes opportunities to carry cargo in both directions may exist. The utilisation factors are listed in Table 11.

Table 11 Capacity utilisation of sea transport for different types of ships

Vessel types	Trade lane / size class	Capacity utilisation factor
BC (dry, liquid and GC)	Suez trade	49%
	Transatlantic trade	55%
	Transpacific trade	53%
	Panama trade	55%
	Other global trade	56%
	Intra-continental trade	57%
	Great lake	58%
Bulk carrier dry	Feeder (5,000 - 15,000 dwt)	60%
	Handysize (15,000 - 35,000 dwt)	56%
	Handymax (35'000 - 60,000 dwt)	55%
	Panamax (60,000 - 80,000 dwt)	55%
	Aframax (80'000 - 120,000 dwt)	55%
	Suezmax (120,000 - 200,000 dwt)	50%
Bulk carrier liquid	Feeder (5,000 - 15,000 dwt)	52%
	Handysize (15,000 - 35,000 dwt)	61%
	Handymax (35'000 - 60,000 dwt)	59%
	Panamax (60,000 - 80,000 dwt)	53%
	Aframax (80'000 - 120,000 dwt)	49%
	Suezmax (120,000 - 200,000 dwt)	48%
	VLOC(+) (>200,000 dwt)	48%
General cargo (GC)	All trades, all size classes	60%
Container vessel (CC)	All trades, all size classes	70%
RoRo vessels	All trades, all size classes	70%
Ferries (RoPax vessels)	All ferry routes	64%

Ships in liner service (i.e. container vessels and car carriers) usually call at multiple ports in the sourcing region and then multiple ports in the destination region (see Figure 6). It is also common that the route is chosen to optimize the cargo space utilisation according to the import and export flows. For example, on the US West Coast a particular pattern exists where vessels from Asia generally have their first call at the ports of Los Angeles or Long Beach to unload import consumer goods and then travel relatively empty up the Western Coast to the Ports of Oakland and other ports, from which then major food exports leave the United States. Combined utilisation factors for container vessels (net load of container spaces on vessels and empty returns) used in ETW is 70% independent of vehicle sizes and trade lanes (see Table 11). This figure equates to the utilisation factor for container ships used by the Second IMO GHG Study 2009 / IMO 2009 /. The Clean Cargo Working Group recommends alike to use this value to recalculate their CO₂ emission values of the container ships considering real utilisation factors /CCWG 2014/.

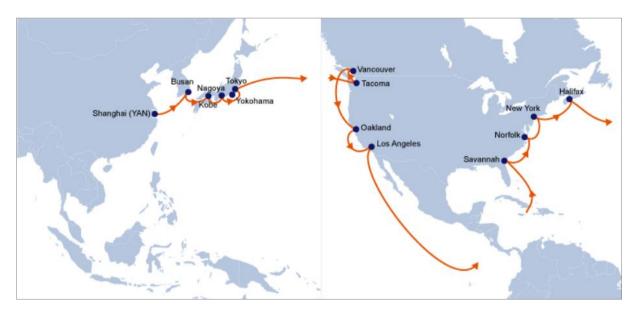


Figure 6: Sample Asia North America Trade Lane by Hapag Lloyd AG²

Capacity utilisation of inland vessels for different cargo types

The methodological approach to inland vessels is in line with the approach for calculating ocean-going vessels. The cargo load factor and the empty trip factor are also combined to a vessel utilisation factor.

The dominant cargo with inland vessels is bulk cargo, although the transport of containerized cargo has been increasing. For bulk cargo on inland vessels, the principle needed to reposition the inland vessel applies. Thus, empty return trips of around 50 % of the time can be assumed. However, no good data is available from the industry. Therefore, it was assumed that the vessel utilisation is 45 % for all bulk inland vessels smaller class VIb (e.g. river Main). Class Va RoRo and class VIb vessels were estimated to have a 60 % vessel utilisation.

Container inland vessels were assumed to have a vessel utilisation of 70 % in analogy with the average container vessel utilisation cited in /IMO 2009/. This reflects less than full loads of containers as well as the better opportunity of container vessels to find carriage for return trips in comparison with bulk inland vessels.

Capacity utilisation of air freight

Since mainly high value volume or perishable goods are shipped by air freight, the permissible maximum weight is limited. Therefore, only the volume goods category is

² Internet Site from 01/10/2014.

considered; other types of goods (bulk, average) are excluded. Table 12 shows the capacity utilisation differentiated by short, medium and long haul (definition see Table 12) /BEIS 2016; Lufthansa 2014; EUROCONTROL 2017; ICAO 2012/. Similar to container ships the utilisation factor refers to the whole round trip of the airplane and includes legs with higher and lower load factors as well as empty trips (like ferry flights). The utilisation factors used for airplane by ETW are included in Table 12. The values for freight refer to the maximum weight which can be transported by freighter or passenger aircraft. The utilisation factors for passenger presented in Table 12 provide information about the seats sold. The latter is used for the allocation of energy consumption and emissions between air cargo and passenger (see chapter 6.5).

Table 12 Capacity utilisation of freight and passenger for aircrafts

	Freight (freighters and passenger aircrafts	Passenger (only passenger aircrafts)
Short haul (up to 1,000 km)	50%	65%
Medium haul (1,001 – 3,700 km)	70%	70%
Long haul (more than 3,700 km)	70%	80%
Sources: BEIS 2016; Lufthansa 2014; EUROCONTROL 2017; ICAO 2013.		

4.3 Basic calculation rules

In ETW the total energy consumption and emissions of each transport mode are calculated for vehicle usage (TTW) and the upstream process (WTT; see chapter 3.3). Thus, several calculation steps are necessary:

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

The following subchapters describe the basic calculation rules for each step. For each transport mode the calculation methodology can differ slightly. More information about special calculation rules and the database are given in Chapter 6.

4.3.1 Final energy consumption per net tonne km (TTW)

The principal **calculation rule** for the calculation of final energy consumption is

Final energy consumption per net tonne km = * specific energy consumption of vehicle or vessel per km / (payload capacity of vehicle or vessel * capacity utilisation of vehicle or vessel)

The corresponding **formula** is

$$ECF_{tkm,i} = ECF_{km,i} / (CP *CU)$$

Abbr.	Definition	Unit
$ECF_{tkm,i}$	Final energy consumption (TTW) per net tonne km for each energy carrier i	[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 (TTW) is the most important key figure for the calculation of total energy consumption and energy related emissions of 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 have to be considered for each energy carrier.
- Final energy consumption depends on various factors (see chapter 4.1). In particular, it should be pointed out that e.g. final energy consumption per kilometre for trucks also depends on capacity utilisation and thus the denominator of the formula.
- As mentioned in chapter 3.1, energy consumption values per tkm combine the steps calculation of energy consumption on a vehicle, train, vessels or airplanes basis and allocation of energy consumption to one single shipment. In the European standard EN 16258 these steps are described consecutively. Nevertheless, the steps can be done in an integrated manner. To fulfil the requirements of EN 16258 it is more important that the VOS is defined in accordance with the European standard and considers the entire round-trips including empty runs. ETW fulfils these requirements 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 chapter 6). However, for all modes the same relevant parameters (final energy consumption of vehicle/vessel, payload capacity and capacity utilisation) are needed.

4.3.2 Energy related emissions per net tonne km (TTW)

The principle calculation rule for the calculation of energy related vehicle emissions is

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

The corresponding formula is

 $EMV_{tkm,i} = ECF_{tkm,i} * EMV_{EC,i}$

Abbr.	Definition	Unit
$EMV_{tkm,i}$	Vehicle emissions (TTW) 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 (TTW) per net tonne km for each energy carrier i	[MJ/tkm]
EMV _{EC,i}	Energy related vehicle emission factor (TTW) for each energy carrier i	[g/MJ]

Explanations:

- The formula is used for all emission components which are directly correlated to final energy consumption (TTW CO2 and SO2 emissions) and for combustion related emissions of fuel driven trains and ships (see chapter 0 to 6.4). The formula is also used for the calculation of standardized TTW energy consumptions in MJ. In this case the energy related energy factors are used (e.g. MJ per litre diesel). To fulfil the requirements of the ISO 14083 the energy factors of the International Organization for Standardization ISO 14083 are used by .
- Based on the ISO the CO₂ equivalents are also calculated by multiplication of the TTW energy consumption with energy related TTW emission factors (e.g. kg CO₂e per litre diesel). For this calculation step the emission factors respectively conversion factors of the ISO 14083 are used without changes. The used values are documented in chapter 6.6 in the annex).
- The CO₂ emission factors used by ETW (e.g. kg CO₂/litre diesel) are based on the same sources like the CO2 equivalent emission factors included in the ISO 14083. Therefore, ETW allows the calculation of CO2 emissions based on the same methodology and the same data sources as the ISO 14083.

4.3.3 Combustion related emissions per net tonne km (TTW)

The principal calculation rule for the calculation of TTW NOx, NMHC and particles emissions (so called combustion related emissions) is

TTW 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

$$EMV_{tkm,i} = EMV_{km,i} / (CP *CU)$$

Abbr.	Definition	Unit
$EMV_{tkm,i}$	Vehicle emissions consumption (TTW) 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 (TTW) of vehicle or vessel per km; normally depends on mass related capacity utilisation	[g/km]
СР	Payload capacity	[tonne]
CU	Capacity utilisation	[%]

Explanations:

- The formula is used for vehicle/vessel emissions of truck and aircraft operation.
- For rail and ship combustion related emission factors are derived from emissions per engine work, not per vehicle-km. Thus, they are expressed as energy related emission factors and calculated with the formula in chapter 4.3.2.

4.3.4 Upstream energy consumption and emissions per net tonne km (WTT)

The principle calculation rule for the calculation of vehicle emissions is

WTT 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

 $EMU_{tkm,i} = ECF_{tkm,i}, *EMU_{EC,I}$

ECU_{tkm,i} = ECF_{tkm,i}, * ECU_{EC,i}

Abbr.	Definition	Unit
$EMU_{tkm,i}$	Upstream emissions (WTT) for each energy carrier i	[g/tkm]
ECU _{tkm,i}	Upstream energy consumption (WTT) for each energy carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HS)	
$ECF_{tkm,i}$	Final energy consumption (TTW) per net tonne km for each energy carrier i	[MJ/tkm]
$EMU_{EC,i}$	Energy related upstream emission factor (WTT) for each energy carrier i	[g/MJ]
ECU _{EC,i}	Energy related upstream energy consumption (WTT) 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 ETW are explained in chapter
- For the calculation of WTT energy and WTT CO₂ equivalent the emission factors of the new ISO 14083 are used for ETW. Only for electricity the ISO 14083 doesn't provide emission factors. Therefore, ETW calculates own emission factors for electricity in accordance to the ISO. The methodology as well as used values is documented in chapter 6.7.

4.3.5 Total energy consumption and emissions of transport (WTW)

The principal calculation rule for the calculation of vehicle emissions is

WTW energy consumption or emissions per transport =

Transport Distance

* mass of freight transported

* (TTW energy consumption or vehicle emissions per net tonne km

+ WTT energy consumption or emissions per net tonne km)

The corresponding formulas are

$$EMT_i = D_i * M* (EMV_{tkm,i} + EMU_{tkm,i})$$

$$ECT_i = D_i^* M^* (ECF_{tkm,i} + ECU_{tkm,i})$$

Abbr.	Definition	Unit
EMT _i	WTW emissions of transport	[kg
ECT _i	WTW energy consumption of transport	[MJ]
Di	Distance of transport performed for each energy carrier i	[km]
M	Mass of freight transported	[net tonne]
$EMV_{tkm,i}$	TTW Vehicle emissions for each energy carrier i	[g/tkm]
ECF _{tkm,i}	TTW energy consumption for each energy carrier i	[MJ/tkm]
EMU _{tkm,i}	WTT (upstream) emission factors for each energy carrier i	[g/tkm]
ECU _{tkm,i}	WTT (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 ETW (see chapter 5).
- WTW 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, if TEU is selected as input parameter in the extended input mode of ETW.
- Using the formula described above for the calculation of WTW energy consumption and WTW CO2 equivalent emissions of transport services fulfils the requirements of EN 16258*. Therefore, the methodology is in accordance with the European standard.

4.4 Basic allocation rules

ETW is a tool which takes the perspective of a shipper – the owner of a freight that has to be transported - that want to estimate the emissions associated with a particular transport activity or a set of different transport options. Within the European standard EN 16258* the transport activity is also called as **transport service**. But ETW may be also used by carriers – the operators and responsible parties for operating vehicles and vessels - to estimate emissions for example for benchmarking. The calculation follows principles of life cycle assessments (LCA) and carbon footprints.

The major rule is that the shipper (freight owner) and carrier take responsibility for the vessel utilisation factor that is averaged over the entire journey, from the starting point to the destination as well as the return trip or the entire loop respectively. This allocation 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 also needs to take responsibility 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 will have to apply a 50 % average load over the entire return journey. This fundamental ecological principle considered by ETW is also a general requirement from EN 16258*. Only by considering the average load factor for the entire journey (as vehicle **operation system** named by the EN 16258) CO₂ calculations fulfil the European standard.

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 are both positive and negative depending on the direction of transport, cancel one another out and the shipper needs to take responsibility for the average emissions. It is the purpose of ETW 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 ETW 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 also be user-defined in the extended input mode)
- **Vehicle/vessel type:** Payload capacity (mass related), final energy consumption and emission factors.
- **Transport relation:** road type, gradient, country/region specific 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 selected freight type and the corresponding specific energy consumption of the vessel. These assumptions avoid the need of different allocation rules for transports with different freight types in the same vehicle, vessel or train. Therefore, no special allocation rules are needed for road and rail transport. This approach is also in accordance with EN 16258*. The European standard requires that the same allocation rules shall be used for the same vehicles.

For passenger ferries and passenger aircrafts with simultaneous passenger and freight transport (belly freight) allocation rules for the differentiation of passenger and freight transport are necessary. These rules are explained in the related chapters. The approaches selected for ETW are also in line with the requirements of the European standard EN 16258*.

5 Routing of transports

5.1 General

For the calculation of energy consumption and environmental impacts ETW has to determine the route between origin and destination for each selected traffic type. Therefore, ETW uses a huge GIS database including worldwide locations and networks for streets, railways, aviation, sea and inland waterways.

Figure 7 Networks of ETW

Name	Туре	Attributes	
Road	Network	Road classes, Ferry, Country code	
Railway	Network	Electrification, European freight corridors, Ferry, Country code	
Ocean shipping	Network	Canal, ECA areas	
Inland waterways	Network	Water classes, Country code, ECA areas	
Air routing	Direct	No network needed, routing on the base of the great circle formula between the airport locations	

Figure 8 Locations of ETW

Name	Туре	Attributes	
City and District names	Location	City name, District name, Country, Location classes, (Translations)	
Zip codes	Location	Country code/ Zip code, City name, Country code	
Stations (UIC-Codes)	Location	Station name, UIC-Code/ station code, Country code	
UN-/Locodes	Location	UN-/Locode, Location name, Country Code, Ports classes, Inland locations CCWG Emission Area	
Airports (IATA-Codes)	Location	IATA-Code, Airport name, Country code, Airport classes	
Longitude/ Latitude	Location	No location layer or attributes are needed	

5.2 Routing with resistances

Depending on the transport type and the individual settings ETW routes the shortest way in consideration of network attributes (resistances). These network attributes are e.g. street classes at the road routing or canals at the ocean routing. If there is a motorway between the origin and the destination the truck will probably use it on its route according to the principle of "always using the path of lowest resistance" defined within ETW. Technically, a motorway has a much lower resistance (factor 1.0) than an urban road (factor 2.5). Thus, a route on a highway has to be more than five times as long as a citystreet before the local street will be preferred. These resistances are used for almost every transport type.

5.2.1 Road network resistances

The street network is divided into different street categories, which are used for the routing as resistances.

Table 13 Resistance of street categories

EcoTransIT World Street Type	Category	Resistance
Motorway	0	1.0
Trunk	1	1.3
Primary	2	1.5
Secondary	3	1.67
Tertiary	4	2.5
Residential	5/6	3.33

Additionally, there are ferry routes within the street network. These ferry routes work like virtual roads where the whole truck is put on the ferry. ETW has different resistances for ferry routes included.

Table 14 Resistance for ferries in the road network

Ferry handling	Resistance
Preferred	1
Normal	5
Avoid	100

5.2.2 Railway network resistances

Railways have the attributes of electrified or diesel line and dedicated freight corridor. If an electrified train is selected, diesel lines can also be used but they get a higher resistance than electrified lines. This is needed if there is no electrified line available or to circumnavigate possible data errors concerning the electrification of the railway net.

The attribute freight corridor is used as a railway highway. Lines with this attribute will be used with preference.

Table 15 Resistance for the railway network

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

Additionally, there are ferry routes within the rail network. These routes work like virtual tracks where the whole train is put on the ferry. ETW has different resistances for ferry routes included.

Resistance for ferries in the railway network Table 16

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

5.3 Sea ship routing

A sea ship normally takes the direct and shortest way between two sea-ports³, harbours, although it often deviates slightly from direct routes due to weather and ocean drift conditions. Therefore, a very large and flexible network is needed. The solution to this is a huge amount of so-called sea nodes, which were placed everywhere in the world close to the coast or around islands. Every sea node is connected with every other sea node as long it does not cross a country side. The result of these connections is a routable sea network.

Container vessels and car carriers often operate as liner traffic and call at multiple ports on a scheduled route. The routing differs from ocean carrier to ocean carrier and may lead to longer distances between a loading and discharging port. Those schedules are not considered in EcoTransIT World today.

Figure 9 Sea network around Denmark /IVE 2019/



Canals and certain sea bottlenecks, e.g. the Kattegat strait, are considered as size restricted passages (by draft, length and width) in this network. Every canal and bottleneck have the attributes of "maximum dead weight tonnes" (DWT) and "maximum TEU capacity" for vessels and is limited to for the classified ship types.

The Suez, Panama and Kiel canals are also included as restricted canals in the ETW sea ship network. Whereas through the Suez Canal even the largest container vessel can pass, the bulk carriers are restricted to 200,000 DWT, which represents the Suez-Max class ships. The Panama-Canal is restricted to bulk carriers up to 80,000 DWT and container carriers up to 4,700 TEU capacity, the Kiel Canal-is restricted to bulk carriers up to 60,000 DWT and container vessels up to 3500 TEU capacity. Additionally, there are small sea areas, like the Kattegat strait between Denmark and Sweden and the entrance to the Great Lakes, next to Montreal, Canada, which are handled as canals and restricted as well (80000 DWT and 4700 TEU for the Kattegat and 60000 DWT and 3500 TEU for the entrance to the Great Lakes).

Ports are considered if they have significant marine traffic. Every port is located and allocated to a specific geographic region (compare Figure 5). On the base of the combination of start and destination location enables the determination of the respective trade lane. For example, on the transatlantic trade, connecting Europe with North America, ETW selects bulk vessels between 35000 and 80000 DWT and container vessels with a TEU capacity of 2000 to 4700 TEU as default ships. If the starting point and destination belong to the same geographic region, an "intra-continental" vessel size is selected. Within Europe an "intra-continental Europe" vessel size is used.

5.3.1 Routing inland waterway ship

The inland waterway network consists an attribute for the inland waterway class. Depending on the ship size and the respective waterway class a waterway can be used or not. Whereas the euro barge 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. Compare also with chapter 6.4.1.

5.4 Aviation routing

In ETW a validation exists if the selected airport is suitable for the flight (compare chapter 5.5). Therefore, all airports are categorized. Depending of the airport category destinations of different distances can be reached.

Table 17 Airport size and reach

Airport size	Reach
Big size	over 5000 km
Middle size	Over 5000 km (but not overseas)
Small size	maximum 5000 km
Very small size	maximum 2500 km

After the selection of the airport, EcoTransIT calculates the distance between the two airports. If the closest airport allows the distance of the flight, it will be selected. If the limit is exceeded, the next bigger airport will be suggested and so on.

The air routing is not based on a network. The calculation of the flight distance uses the Great Circle Distance (GCD). By definition it is the shortest distance between two points on the surface of a sphere. GCD is calculated by using the geographical coordinates of the two airports which are selected by the EcoTransIT user.

However, the real flight path is longer than the GCD due to departure and arrival procedures, stacking, adverse weather conditions, restricted or congested airspace /Kettunen et al. 2005, Gulding et al. 2009, Reynolds 2009/. Therefore, the European standard EN 16258 as well as the European Emission Trading System (ETS) and the ISO 14083 prescribed adding a blanket supplement of 95 km to the GCD for each leg of flight. This approach is also adopted by ETW. Based on this requirement the real flight distance is calculated by using the following formula:

In ETW airplanes have a maximum reachable distance (so called maximum design range). If the distance between the airports exceeds this distance ETW cannot calculate the emissions for this specific airplane and the error message "Route not found" will be applied. To avoid this error the user has the possibilities to insert a stop-over as via point in the transport chain or to calculate with a hybrid plane.

A hybrid airplane is a mixture of the belly freight airplane B747-400 and the freighter B747-400F (see chapter 5.5). The maximum design range of this hybrid plane is 8,230 kilometres. If the flight distance exceeds this range an additional virtual stopover is automatically included for each 8,230 kilometres. If stopovers are considered for each of the legs a blanket supplement of 95 km is added to the GCD.

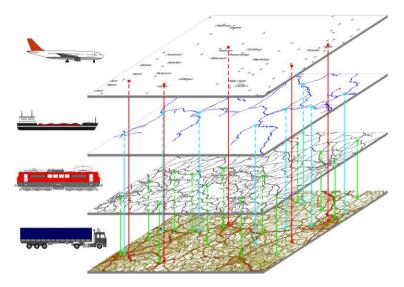
Determination of transport points within combined 5.5 transport chains

The routing is available on the different networks for road, railway, ocean, inland waterways and air routes. Depending on the selected mode, ETW determines a route on the respective transport type network.

All networks are connected with so-called transfer points. These transfer points enable the change of a network. Thus, it is possible to calculate complex transport chains with ETW.

Furthermore, ETW has an algorithm to determine the probable transfer point of the transport chain. This is needed if the user wants to calculate a sea shipping transport and defines zip codes as origin and destination (instead of two UN-/Locodes for the ports). In this case, ETW has to determine the closest situated suitable ports to the origin and destination. After the determination of these transfer points and the routing, algorithm locates the routes (in the normal case on the street network) to these transfer point ports. Finally, the main routing between the two ports will be applied on the base of the ocean sea shipping network.

Figure 10 Principle of nodes between different networks



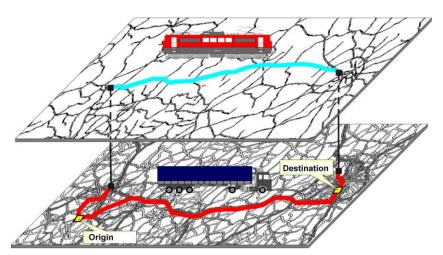
If a detection of a transfer point is needed, ETW determines the geographically nearest transfer points (as-the-birds-fly) to the respective origin and/or destination. The selection of the transfer points is also influenced by the size range of the respective airport or harbour. Thus, a container-based Suez trade will always start and end with a large classified harbour or a medium haul flight needs at least medium classified airports.

The automatically determination of transfer points could create unrealistic routes because the located transfer point need not be the most suitable choice and could e.g. create needless detours. To avoid this, it is recommended to define the transfer points as via nodes and select directly by this way the correct transport chain.

5.5.1 Definition of side tracks for rail transports

If a transfer point is a station the feeder transport will be calculated regular as a truck transport. The attribute "side-track available" enables the calculation as a train transport (instead the truck). This could be needed if a shipper has a railway connection (side track) which is e.g. not within the ETW GIS-data. In this case, EcoTransIT determines the route on the base of the street network but calculates it as a railway transport.

Figure 11: Route selection in road and rail network from origin to destination



6 Methodology and environmental data for each transport mode

Within the next chapters the methodology for the calculation of energy consumption and emissions of freight transport as well as the data sources used are presented for each mode of transport in detail. The methodology for the calculation of energy consumption and CO₂ equivalent emissions are in accordance with the European standard EN 16258*. As required by the standard all used data sources and allocation methodologies are documented in the following chapters.

6.1 Road transport

6.1.1 Classification of truck types

ETW is focused on international long-distance transports. These are typically accomplished using truck trains and articulated trucks. Normally, the maximum gross tonne weight of trucks is limited, e.g. 40 tonnes in most European countries, 60 tonnes in Sweden and Finland and 80,000lbs in the United States on highways. For feeding or special transports, other truck types are used. In ETW, the gross weight classes for all vehicle sizes used for cargo transport are as follows:

Table 18 Truck size classes in ETW

EU/Japan	EPA
Truck >3.5-7.5t	Truck >8,500-16,000lbs
Truck >7.5-12t	Truck >16,000-26,000lbs
Truck >12-20t	Truck >26,000-44,000lbs
Truck >20-26t	Truck >44,000-60,000lbs
Truck >26-40t	Truck >60,000-80,000lbs
Truck >40-50t	Truck >80,000-100,000lbs
Truck >50-60t	Truck >100,000-130.000lbs
Truck >60t	Truck >130,000lbs

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 long-distance transports, and therefore it is not included.

The European emission standard is used in most countries worldwide for emission legislation. Other relevant standards are the US EPA emission regulations and the Japanese standards. The following table shows the emission standards used in ETW.

Table 19 Emission standards in ETW

EU	EPA	Japan
Euro-I (1992)	EPA 1994	JP 1994
Euro-II (1996)	EPA 1998	JP 1997
Euro-III (2000)	EPA 2004	JP 2003
Euro-IV (2005)	EPA 2007	JP 2005
Euro-V (2008)	EPA 2010	JP 2009
Euro-VI (2013)	n.a.*	JP 2016
Euro-VI a-c (2013)	n.a.*	JP 2016
Euro-VI d-e (2019)	n.a.	n.a.

^{*} voluntary NOx standard from CARB 2015 is not implemented due to the lack of CARB 2015 certified diesel engines

6.1.2 Final energy consumption and vehicle emission factors (TTW)

The main sources for final energy consumption and vehicle emission factors is the "Handbook emission factors for road transport" (HBEFA) /INFRAS 2022/ for trucks with EU emission limits and the MOVES model for EPA standard /EPA 2014/.

The influence of the load factor is modelled according to the Handbook of Emission Factors /INFRAS 2022/. Accordingly, the fuel consumption of an empty vehicle can be 1/3 below the fuel consumption of the fully loaded vehicle. This influence can be even stronger depending on driving characteristics and the gradient.

Energy consumption and emissions also depend on the driving pattern. Three typical driving patterns, one for highway traffic and one for traffic on extra urban roads and for traffic on urban roads, are considered by ETW.

Another parameter is the **gradient**. The gradient takes into account country-specific factors, which represent the average topology of the country ("flat", "hilly", and "mountains"). ifeu and INFRAS analyses for Germany /ifeu 2002b/ and Switzerland /INFRAS 1995/ show 5-10 % higher energy consumption and emissions for heavy duty vehicles if the country specific gradients are taken into account. No significant differences could be determined between the countries of Germany and Switzerland. However, for these analyses, the entire traffic on all roads has been considered.

The share of gradients for the different countries in international road transports can only be estimated. No adjustments will be made for the "hilly countries" such as Germany (and all others except the following named), while energy consumption and emissions are assumed 5 % lower for the "flat countries" (Denmark, Netherlands and Sweden) and 5 % higher for the "mountainous countries" Switzerland and Austria. For all regions outside Europe the values for "hilly" are used.

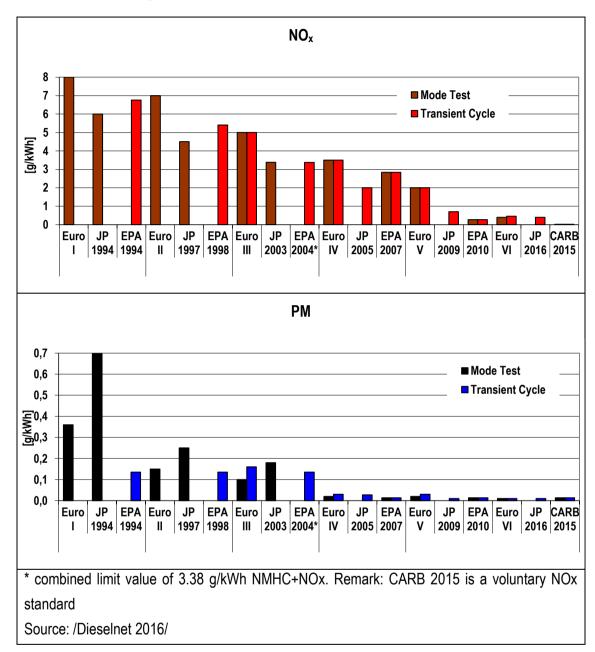
The energy and emission factors of road transport for ETW are derived from the Handbook of Emission Factors (HBEFA 4.2) /INFRAS 2022/ for trucks with Euro standards. For the determination of values for trucks in North America several sources were analysed:

- emission limit values for the EPA standard compared with the EU standard /Dieselnet 2014/
- the emission model MOVES2014 to compare emission factors and energy consumption of trucks by road type, registration year and size /EPA 2014/
- further statistical data (/USCB 2004/, /USDOT 2007/, /USDOE 2009/) on truck size classification, average utilisation and energy consumption

Comparison of Emission standards

A comparison of the U.S., EU and Japanese emission limit values provides insight into the potential difference between the trucks exhaust emission characteristics for these countries. (See

Figure 12)



EU, Japanese and U.S. Emission Limit Values for Heavy Duty Diesel Vehicles by Emission Standard Figure 12 and Testing Procedure

Default emission standards and fuel quality for the regions

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.

Users of ETW can choose newer emission standards than the default value. It must be noted, that the sulphur content of the diesel fuel restricts several exhaust gas treatment technologies for newer emission standards /UNEP 2007/.

- Diesel oxidation catalysts (DOC), 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 for 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. Direct emission factors for SO2 are derived from the sulphur content of the fuel. For Europe, the value is 10 ppm (= 0.47 kg/TJ). In several countries this value is a lot higher, reaching 5000 ppm or even 8000 ppm in Iran.

In the previous version of ETW, Euro V was used as default emissions standards worldwide /ifeu / INFRAS / IVE 2014/. Based on the above considerations, all default values were updated. 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 (introduced around 2008) or at least EURO II (see table below).

Table 20 Sulphur content of diesel fuel [ppm] and default emission standards for trucks

Region	Code	Sulphur content [ppm]	default emission standard	emission legislation / latest standard
Africa	AFR	5000	EURO II	-
Africa	ZA	500	EURO II	-
	ASP	5000	EURO II	-
	CN	50	EURO III	EURO IV
	HK	10	EURO IV	EURO V
Asia and Pacific	IN	350	EURO II	EURO III
	JP	10	JP 2009	JP 2016
	IR	8000	EURO II	-
	KR	50	EURO IV	EURO IV
Australia	AU	10	EURO V	EURO V
Middle East	MIE	5000	EURO II	-
World	WRLD	5000	EURO II	-
	CSA	5000	EURO II	-
Central and South	BR	500	EURO III	EURO V
America	CL	15	EURO III	EURO V
	MX	500	EURO III	EURO IV
	EUR	500	EURO II	-
Europe	ВА	350	EURO II	-
	EU 28	10	EURO VI	EURO VI

	ME	10	EURO II	-
	RS	10	EURO III	EURO III
	TR	10	EURO IV	EURO VI
	СН	10	EURO VI	EURO VI
	IL	10	EURO V	EURO V
Nouth Amorica	CA	15	EPA 2010	CARB 2015
North America	US	15	EPA 2010	CARB 2015
Russia and FSU	FSU 15	500	EURO II	-
หนรรเล สกต ครบ	RU	50	EURO III	EURO IV

Remarks: CN: nation-wide sulphur values; some regions have lower limit values. CARB 2015 is an optional standard.

Sources: /UNEP 2016/; dieselnet.com; integer.com; transportpolicy.net; energy.gov.il; trend news agency 2013

So far, the default size for any truck in ETW was the 26-40 t truck, which is the most often used truck size in the EU and some other countries worldwide. Only in Sweden extra-large trucks with a GVV of 60t are being used more often. However, there is a considerable number of countries where smaller trucks are being widely used. Therefore, we have integrated a default truck size for the different countries into the tool.

Data for these default sizes was taken from Eurostat, the TRACCS database and partially validated by looking at the truck size legislation in the different countries. For non-EU countries, expert judgement was used and complimented by internal data from carriers operating in those regions.

Table 21 Default sizes for trucks

Region	Code	Default truck size
461	afr	Truck >20-26t
Africa	ZA	Truck >20-26t
	asp	Truck >12-20t
	CN	Truck >20-26t
	HK	Truck >20-26t
Asia and Pacific	IN	Truck >20-26t
	JP	Truck >20-26t
	IR	Truck >12-20t
	KR	Truck >12-20t
Australia	AU	Truck >26-40t
Middle East	MIE	Truck >20-26t
World	Wrld	Truck >26-40t
Central and	csa	Truck >12-20t
South America	BR	Truck >20-26t

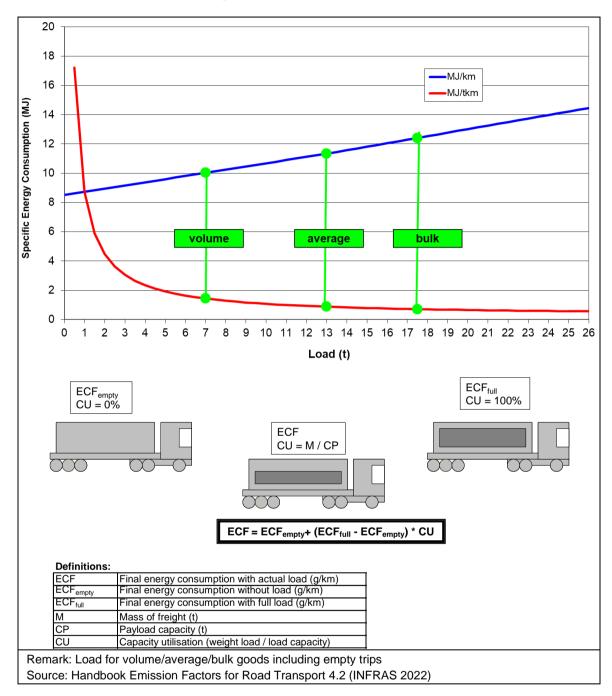
	CL	Truck >12-20t	
	MX	Truck >20-26t	
Europe	eur	Truck >26-40t	
	BA	Truck >26-40t	
	EU 28 (without SE)	Truck >26-40t	
	ME	Truck >26-40t	
	SE	Truck >50-60	
	RS	Truck >26-40t	
	TR	Truck >26-40t	
	CH	Truck >26-40t	
	IL	Truck >20-26t	
North America	CA	Truck >60,000-80,000lbs	
North America	US	Truck >60,000-80,000lbs	
Bussis and ESU	rfs	Truck >26-40t	
Russia and FSU	RU	Truck >26-40t	

6.1.3 Final energy consumption and vehicle emissions (TTW)

For road transport with trucks, the general calculation rules described in chapter 4.3 are applied. A speciality is the dependence of final energy consumption and vehicle emissions from load weight:

The energy consumption and emissions of a truck depend on the specific energy consumption of the vehicle per kilometre and increases with higher load weights. Thus, the energy consumption per kilometre is a function of the capacity utilisation.

The following figure shows an example for the energy consumption per vehicle-km as a function of load weight, including values for freight types.



Energy consumption for heavy duty trucks (40 t vehicle gross weight, Euro-VI a-c, motorway, hilly) Figure 13: as a function of load weight

For the calculation of energy consumption and emissions per net tonne km, the basic calculation rules are applied (see chapter 4.3).

Table 22 shows one set of TTW energy and emission values. For the calculation of TTW CO₂- and CO₂e-emissions the fuel emission factors are applied (see chapter 6.6)

Table 22 Energy consumption and emissions (TTW) of selected diesel trucks with different load factors in Europe (Motorway, average gradient for hilly countries)

		empty	Average*	full
Vehicle Type		0%	60%	100%
	I	Energy Consumption (M.	J/km)	
Truck Euro VI d-e	>3,5-7,5t	5,8	6,4	6,8
	>7,5-12t	6,3	7,1	7,6
	>12-20t	7,0	8,5	9,5
	>20-26t	7,8	9,8	11,2
	>26-40t	8,4	11,9	14,4
	>40-50t	9,2	13,9	17,2
	>50-60t	11,3	16,8	20,6
	>60t	14,9	23,2	29,0
NOx-Emissions (g	/km)			
Truck >26-40t	Euro-I	7,7	10,5	12,3
	Euro-II	7,9	10,7	12,6
	Euro-III	5,9	8,1	9,7
	Euro-IV	3,7	3,9	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-l	0,483	0,473	0,497
	Euro-II	0,318	0,314	0,333
	Euro-III	0,304	0,286	0,305
	Euro-IV	0,026	0,032	0,036
	Euro-V	0,036	0,040	0,044
	Euro-VI a-c	0,015	0,019	0,023
	Euro-VI d-e	0,025	0,026	0,028
PM-Emissions (g/	km)	•		
Truck >26-40t	Euro-I	0,269	0,329	0,377
	Euro-II	0,129	0,163	0,192
	Euro-III	0,148	0,149	0,172
	Euro-IV	0,038	0,044	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

*average usage not including empty trips

Rigid lorries and articulated trucks in the same gross weight class can have different empty weights, depending on the body type (e.g. curtainsider vs. box). Thus, the user of EcoTransIT World can enter their own empty weights into the calculation. Using an

interpolation, emission factors for slightly different truck masses were derived from the original HEBFA 4.2 data.

6.1.4 Alternative fuel trucks

Worldwide the vast majority of the trucks uses diesel as fuel. Due to the potential emission reductions and lower fuel costs some fleet managers invested into alternative fuels recently. In 2014 around 200,000 heavy or medium-heavy trucks in Europe (most of them in Eastern Europe) and 350,000 heavy or medium-heavy trucks in China were using CNG or LNG according to the natural gas vehicle association (NGVA). Electric trucks are even less common but have a growing importance (see Table 23).

Table 23	Market situation	for trucks w	ith alternative fuels

Drivetrain	Market share worldwide	Examples for pioneer markets	Examples for truck manufacturers
Diesel	Market leader	worldwide	all
CNG	Niche	China, USA, Sweden	e.g. IVECO, MAN, Daimler, SCANIA, Renault, Volvo, Cummins Westport, Freightliner
LNG	Niche	China, USA, Netherlands, Spain	IVECO, SCANIA, Cummins Westport, Freightliner
Dual Fuel (CNG/LNG - Diesel)	Niche	China, USA, UK	MAN, Cummins Westport
Battery electric	Niche	Germany, Austria	MAN, IVECO, Daimler (test)
Overhead catenary	Pilot phase	Sweden, Germany, USA	Siemens (test), Scania
Fuel cell	Pilot phase	Germany, USA	Daimler, Volvo
Source: ifeu analysis		·	

Having already a niche market, the truck types given in Table 24 are included in EcoTransIT. LNG trucks are common for heavy trucks (>26 t GW) while battery trucks are used for smaller size classes (<26 t). Being a rather young technology, only gas-powered trucks with Euro V or Euro VI standard are considered. For dual fuel, truck manufacturers so far have hesitated in bringing Euro VI dual fuel trucks on the market due to the challenge of keeping the emission limits /DLR et al. 2015/.

Table 24 Truck types with alternative fuels in EcoTransIT

Drivetrain	Size (gross vehicle weight)	Emission standard	
CNG	3,5-40 t	EEV/Euro V	
		Euro VI	
LNG	26-40 t	EEV/Euro V	
		Euro VI	
Dual Fuel (LNG/Diesel)	26-40 t	EEV/Euro V	

Electric (Battery) 3,5-40 t -

Availability of refuelling infrastructure

CNG and LNG trucks require a dedicated refuelling infrastructure which is not yet available in a similar amount to diesel stations or not available at all in some countries⁴. Also, fast charging stations for battery vehicles, especially trucks, are not yet common. Therefore, the operation of trucks with alternative fuels is limited to certain routes and applications at the moment. EcoTransIT has no information on the spatial availability of alternative fuel stations and ETW users have to check availability by themselves. It has to be noted, that extra distances for refuelling might also increase the emissions.

Table 25 gives the number of CNG and LNG stations in the countries with the highest density of these stations per 1000 km². The number of CNG stations is in most countries higher than for LNG stations. However, the CNG stations are often designed for light duty vehicles and the availability for trucks can be much lower.

When calculating a transport chain EcoTransIT provides the number of refuelling stations in a starting country. But as mentioned above, the exact availability for a specific transport chain (or route) has to be checked from other source, e.g. www.gibgas.de for the EU or www.afdc.energy.gov for the USA.

⁴ However, the installation of a fuel infrastructure is supported by some countries, e.g. in the EU for CNG and LNG within the next decade in order to fulfill the alternative fuel infrastructure directive (2014/94/EU).

Table 25 Availability of CNG and LNG refuelling stations in the top 10 countries respectively (ranked by the number of stations per 1000 km²)

Fuel	Region	Country	Stations	Stations per 1000 km ²
CNG	Europe	Netherlands	194	5.72
	Europe	Switzerland	167	4.18
	Europe	Italy	1,022	3.47
	Europe	Germany	892	2.56
	Europe	Austria	205	2.49
	Europe	Luxembourg	6	2.32
	Europe	Czech Republic	173	2.24
	Europe	Belgium	56	1.85
	Asia and Pacific	South Korea	196	1.63
	Asia and Pacific	Iran	2,360	1.54
LNG	Europe	Netherlands	16	0.47
	Asia and Pacific	China (including Hong Kong)	3,500	0.38
	Europe	United Kingdom	14	0.06
	Europe	Spain	25	0.05
	Europe	Portugal	4	0.04
	Europe	Italy	6	0.02
	Europe	Sweden	6	0.01
	Europe	France	7	0.01
Ī	Europe	Germany	3	0.01
Ī	North America	United States	76	0.01
Source: I	EU: NGVA, 2017 data; No	n-EU: NGV Global, 2014 data		

Specific energy consumption and emissions of alternative fuel trucks (TTW)

Only a few measurements are available already for alternative fuel trucks Due to the current lack of information, instead of detailed energy consumption and emission factors (i.e. per size class, road type and load), average correction factors compared to similar diesel trucks are applied (see Table 26).

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 for most gas trucks. 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. Dual fuel trucks use compression ignition (diesel) engines and are therefore assumed to have the same fuel efficiency than diesel trucks. The average ratio of natural gas (LNG) to diesel in energy consumption of dual fuel trucks for ETW is 60:40, based on /DLR et al. 2015/ and own assumptions.

Less information is available on real world air pollutant emissions (NOx, NMHC and PM) of gas trucks. It is assumed that the emissions are similar to the diesel trucks, except that Euro V CNG and LNG trucks have lower PM emissions, which are similar to Euro VI diesel trucks. This is due to the fact that spark ignited gas engines have very low PM emissions, even without using particle filters /TNO 2017/. The SOx emissions depend on the sulphur content, which is assumed to be 3.5 ppm and therefore lower than for diesel /TNO 2011/.

Table 26	TTW emission factors of alternative fuel compared to diesel trucks
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Vehicle Type (fuel, size, emission standard)	EC	NOx	NMHC	PM
CNG, all size classes, Euro V	+24%	sin	nilar	Euro VI
CNG, all size classes, Euro VI	+24%		similar	
LNG, all size classes, Euro V	+24%	sin	nilar	Euro VI
LNG, all size classes, Euro VI	+24%		similar	
Dual Fuel (LNG/Diesel), all size classes, Euro V		sin	nilar	
Source: (DLR et al. 2015), ifeu assumptions				

Integration of gas-powered trucks into HBEFA 4.2 is still at an early stage, but follows a similar methodology with simple correction factors comparing gas to diesel trucks. It was thus decided to stick with the previously done assessment of the environmental performance of gas trucks.

It has to be mentioned that the given assumptions provide only a rough picture and include uncertainties which can be hardly quantified at the moment. With increasing market entrance of alternative fuel trucks and availability of measurement data the emission factors should be reviewed.

Furthermore, the processes for energy generation greatly differ for the different truck types (see chapter 6.6 on WTT emissions). These emissions have to be included for an adequate comparison of emissions, especially for electric trucks. Emissions from vehicle construction are not yet within the scope of EcoTransIT, but can have a relevant share of lifecycle emissions, i.e. for batteries (see also chapter 3.3.1).

Battery electric trucks are newly updated in HBEFA 4.2. They have no tailpipe emissions and use electricity as their only fuel. The assessment for those trucks was done using the VECTO model, their energy demand is however modelled for a potential future vehicle (2025+) since battery-electric trucks are almost non-existent today. These batteryelectric trucks provide a range of 350 km and have a higher empty weight than their conventional counterparts due to the addition of the battery.

Size Class	Empty 0%	Average 60%	Full 100%	
Truck <7.5t	3,2	3,5	3,7	
Truck 7.5-12t	3,3	3,7	4,0	
Truck 12-20t	3,7	4,2	4,5	
Truck 26-40t	5,9	7,1	7,8	
Source: Handbook Emission Factors for Road Transport 4.2 (INFRAS 2022)				

Table 27 TTW energy consumption of electric trucks

Furthermore, with this version fuel cell electric trucks are also included into ETW, here the same weight classes as for battery-electric trucks are used. Due to the lower efficiency of the drivetrain, fuel cell electric trucks have on average a 42% higher energy demand than battery-electric trucks.

Rail transport 6.2

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 ETW 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 actual version of ETW allows to use special train types for dedicated transport tasks.

6.2.1 Train Types

6.2.2 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. Australia, Canada, China, USA. Typical train weights in these countries are about 4,000 tonnes and more. For this reason, ETW must cover a wide range in regards to train weight.

Train type	Gross tonne weight train	Empty weight wagon	Capacity wagon	LF	ETF
Light	500 t				
Average	1000 t			Bulk: 100 %	Bulk: 80 %
Large	1500 t	23 t	61 t	Average: 60%	Average: 50%
Extra Large	2000 t			Volume: 30%	Volume: 20%
Heavy	5000 t				
Source: ETW definitions and assumptions					

Table 28 Definition of general train types in ETW

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 2012, SNCF 2012/. In ETW average values for these train types are used. They mainly reflect the European situation.

Definition of dedicated train types in ETW Table 29

Train type	Gross tonne weight train	Empty weight wagon	Capacity wagon	LF	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: DB Cargo, SNCF, ifeu	assumptions				

6.2.4 Final energy consumption (TTW)

In ETW the final energy consumption of trains is calculated using functions, which are based on actual values 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. 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 GWT with 10 tonnes increments and coarse weight classes for GWT >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 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 ETW:

< 1000 GTW (power function):

$$EC_{spec}$$
 [Wh/Gtkm] = 369.46 * GTW-0.457 (EC_{spec}: specific Energy Consumption, GTW: Gross Tonne Weight)

 \geq 1000 and < 2000 GTW (power function):

$$EC_{spec} \ [Wh/Gtkm] = 3137 * GTW^{-0.767}$$
 (EC_{spec}: specific Energy Consumption, GTW: Gross Tonne Weight)

≥ 2000 GTW (linear function):

$$EC_{spec}$$
 [Wh/Gtkm] = -0.0007 * GTW+ 10.577 (EC_{spec}: specific Energy Consumption, GTW: Gross Tonne Weight)

The following diagram shows some of the actual values compared to the former function of EcoTransIT from 2009 (for hilly countries) as well as the new functions mentioned above.

The following conclusions can be stated:

- Nearly all values reside below the former EcoTransIT function from 2009.
- 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.

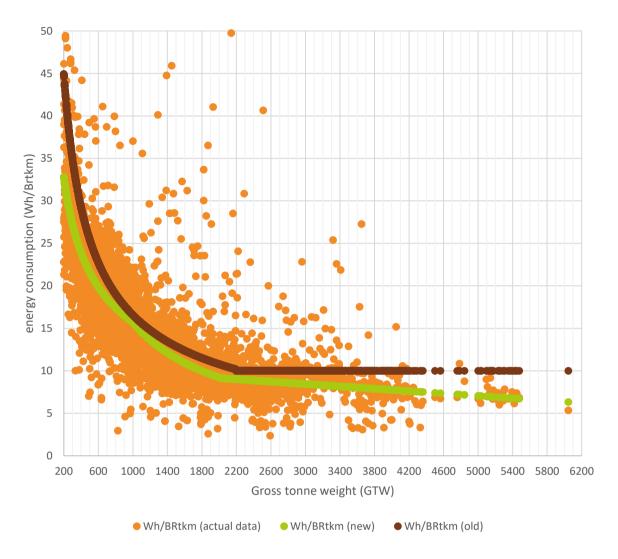


Figure 14: Energy consumption of electric trains – actual data and old/ new functions

We no longer differentiate between hilly, mountainous or flat countries, since we lack sufficient data to derive a suitable correction factor. Furthermore, SBB data showed that the energy demand in Switzerland is in line with the data from other, less mountainous countries like Germany or France (which could be due to more tunnels leading through the Alps like the new "Gotthard Basistunnel").

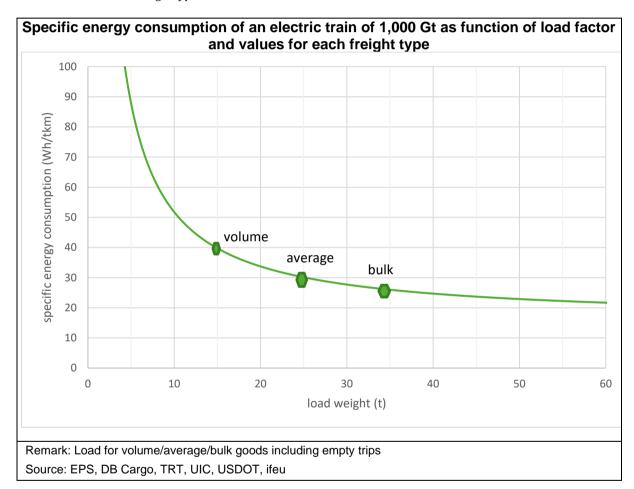
The specific energy consumption per net tonne km is calculated for each train type with the following formula:

> Specific energy consumption [Wh/Ntkm] = Energy consumption of train [Wh/Gtkm] / Relation Nt/Gt of freight (including empty trip factor)

0.40 for volume freight Relation Nt/Gt = 0.52 for average freight 0.60 for bulk freight

The following figure shows the specific energy consumption as a function of the net tonnes/gross tonne relation for a 1000-tonne electric train and the values for each freight type.

Figure 15 Specific energy consumption of an electric train of 1,000 Gt as function of load factor and values for each freight type



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

Table 30 Specific final energy consumption for selected electric trains

		Final Energ	y Consumption	
Train Type	Train		Freight	
		Bulk	Average	Volume
Unit	Wh/Gtkm		Wh/Ntkm	
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 vessel weight (container,	truck, semi-traile	er, swap body)		

Source: DB Cargo, SNCF, RailCargo, ifeu assumptions

6.2.5 Energy consumption of diesel trains

The available energy data for diesel traction ranges between 2.6 and 9.7 g/gross tonne km /Railways companies 2002/. Other statistics show a similar range /UIC 2009/. The statistical uncertainties can be attributed to the unreliable allocation of the fuel consumption to different users (passenger and goods transport, shunting, etc.). Therefore, the primary energy consumption of diesel traction is estimated on the basis of the primary energy consumption of electric traction. This procedure can be used, because the total efficiency of diesel traction (including the production of fuel) is similar to the total efficiency of electric traction (including electricity generation).

So, the same functional dependence as that of electric traction is taken and has to be divided by the efficiency of the diesel-electric conversion for final energy consumption of 37 %. (See Chapter 6.6.1).

The following table shows the resulting specific energy consumption per Gtkm and Ntkm for different diesel trains and freight types. Some available values of heavy trains from China and statistical averages for Canada and USA are added. The values of North

American railways are higher than values from energy function (similar to the large train in the formula). For this reason, additional energy consumption for North American railways could be possible, but we propose to use this formula also for North America as well on account of the small North American database available.

Table 31 Specific final energy consumption for diesel trains

	Final Energy Consumption				
Train Type	Train		Freight		
		Bulk	Average	Volume	
Unit	Wh/Gtkm		Wh/Ntkm		
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		
Source: DB Cargo, SNCF, ifet	ı EPS 2005,	USDOT			

Emission factors for diesel train operation (TTW)

Similar to diesel engines for road and inland ship transport, the emission performance of locomotive engines strongly depends on the engine technology. In the past years the UIC, the EU and US implemented emission limits for new engines in several stages, thus reducing specific emissions for newer engines. This fact should be considered in ETW by providing different emission factors by emissions stage, like already available for road and inland ship transport.

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

Table 32: Emission standards for diesel trains (NOx, NMHC, PM)

Standard	Manufacture year	HC	NOx	PM				
International UIC (g/kWh)	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 Illa	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: www.dieselnet.com								

Determination of emission factors for ETW

For ETW 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 ETW a PM value for UIC 1 is added, based on engine data from engines with manufacture year 1997 and before from [IFEU, 2003]. Table 33 shows the resulting emission factors used in ETW.

Standard	Manufacture year	HC	NOx	PM				
International: UIC (g/kg)	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 k	W (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				

Emission factors for diesel locomotives (freight transport) in ETW available in the expert mode Table 33:

Country specific regulations and default values

The emissions values in Table 33 can be compared with existing data from railway companies and the recent default values of EcoTransIT (see Table 34). The comparison shows, that the former ETW-values have a level between UIC 1 and UIC 2 and the average cargo fleet of DB in 2015 lies between UIC 2 and Stage IIIa. Other data could not be evaluated so far.

Table 34: Emission factors for diesel locomotives (freight transport) from different sources

Standard	Manufacture year	НС	NOx	PM	
Average values (g/kg), different sources					
ETW 2010	All	4,6	48,3	1,30	
DB 2016	All	2,6	42	0,96	

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

- 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 improvement we recommend to ask the 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, the extended mode in ETW gives an additional option to choose a particle filter. As default a value of 0.012 g PM/kg is used.

6.2.6 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 center which chooses the track.

The energy consumption for shunting is calculated for a typical shunting cycle (MTUshunting), 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.

6.3 Sea transport

6.3.1 Overview

The sea transport emission factors in ETW are largely based on the findings of the Fourth Greenhouse Gas study of the International Maritime Organization (IMO) /IMO 2020/. Basically, fuel consumption and emission factors for main engine, auxiliary engine and boiler were derived in a bottom-up approach from IMO data for individual ship categories and size classes and validated using worldwide fuel consumption and CO2 emissions for 2018 from /IMO 2020/. These factors are then aggregated to

- a) the vessel types and size classes available in the Extended input mode of ETW (Table 38), and
- b) the trade lanes (see chapter 6.3.4), which are automatically assigned based on the chosen origin and destination in ETW.

The resulting fuel consumption and emission factors are further adjusted to a default or user-specified speed reduction and cargo utilization.

The "IMO 2020" regulation, which entered into force in 2020 and limits the sulphur content in ship fuel oil to 0.5% /IMO 2019/, as well as the general transition to more climate-friendly technologies, result in rapidly changing fuel mixes used in sea transport. This is considered in ETW by regularly updated fuel mix data, which provide for the correct weighting of fuel-specific consumption and emission factors inside and outside emission control areas (ECAs).

The following vessel types are differentiated:

- General Cargo Vessels
- Dry Bulk Carriers
- Liquid Bulk Carriers
- **Container Carriers**
- Roll-on-Roll-off vessels

Other vessels are not included in ETW because of their differing cargo specifications and lower relevance for the likely ETW user. Those vessel types include LNG and LPG gas carriers as well as car carriers. Ferries are not included in this section of the report because they are treated like extensions of the road network and are thus presented in the chapter on land transport.

6.3.2 Power demand

The basic fuel consumption and emission factors are derived for each IMO ship type and size class, separately for main engine, auxiliary engine, and boiler, based on the methodology used in the Fourth IMO Greenhouse Gas Study from 2020 (see /IMO 2020/, Table 81 in Annex N for ship types and associated parameters).

To account for emissions in port and return journeys, fuel consumption is modelled separately for main engine, auxiliary engine, and boiler, for a virtual one-year period in the standard assumption. The emission and consumption factors are expressed per tkm (e.g. in g/tkm). If reduced vessel speeds are modelled, the vessel's activity extends the one-year period in order to deliver the same transport services (see Chapter 6.3.5).

The power demand in kWh/tkm of the main engine is derived based on the following formulas. First, the power demand of each IMO ship type and size class 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:

= Propulsive power demand of the main engine in kW $W_{ME,Ship}$

 W_{REF} = Rated average main engine power at MCR [kW] /IMO 2020, Table 81 in Annex N/

= Actual draught and design draught of the ship. t, t_{REF} Since no data on actual draught are available, the ratio of the two is currently assumed to equal 1 in ETW.

= Actual speed and design speed of the ship. This ratio is also set to 1 at v, v_{REF} first, so that the power demand at design speed results from the equation. The influence of actual or user-defined speed is considered later in the calculation process (see Chapter 6.3.5).

 CF_{Ship} = Ship-specific correction factor. Based on Table 44 in /IMO 2020/. For large container carriers, partially calibrated to better match consumption reported by CCWG members.

= Correction factor for the influence of weather (wind, waves). Based on CFWeather Table 44 in /IMO 2020/.

= Correction factor for the influence of hull fouling/hull roughness. Based $CF_{Fouling}$ on Table 44 in /IMO 2020/.

The result of 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 ship. By default, dead weight tonnage * 0.95

CU= Average capacity utilization of the ship in %, based on /IMO 2009/, /IMO

2020/, and CCWG

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

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

With

 $W_{A.B}$ = Power demand of the auxiliary engine or boiler in kWh/tkm

Number of days at sea per year /IMO 2020/ d_{sea}

= Auxiliary engine/boiler load at sea [kW] /IMO 2020/ L_{sea}

 d_{port} Number of days in port per year

= Auxiliary engine/boiler load in port [kW], /IMO 2020/ L_{port}

Number of auxiliary engines/boilers /IMO 2020/ n

Dist = Annual distance driven by the ship, estimated as

 $d_{sea} * 24 * v$

6.3.3 Fuel/technology mix and derivation of consumption and emission factors

Based on the fuel mix, i.e. the energy share of each fuel/technology type consumed inside and outside emission control areas (ECAs), weighted average emission and consumption factors for each IMO ship type and size class combination, and inside/outside ECAs are calculated.

The fuel and technology types currently considered in ETW, along with their energy shares inside/outside ECAs in the year 2020, are listed in Table 35. It should be noted that:

- Residual and distillate origin of fuels (e.g. ULSFO-RM vs. -DM) are not differentiated in ETW, as the impact of this difference is not relevant for ETW outputs and available activity data sources contain it.
- The energy share inside/outside ECAs is based on data from the Clean Cargo Working Group (CCWG), an association of container carriers representing about 85% of container trade. It is representative for container carriers only. However, for other ship types, no data source could be located so far that would allow the distinction inside/outside ECAs. Therefore, the energy shares from CCWG are assumed to be valid for other ship types as well.

Table 35: Fuel types considered in ETW for sea transport

ETW fuel type	S reduction	S	CO2	Energy	Energy sha	re in 2020
	technology	content in fuel	EF [g/g]	content [MJ/kg]	Inside ECA	Outside ECA
HFO (Heavy fuel oil; also called	Scrubber	2.60%	3.1140	40.5	0.0%	29.0%
HSFO, HSHFO)	No Scrubber	2.60%	3.1140	40.5	13.4%	15.0%
Blends (fuel oil blends or hybrid fuels; also called VLSFO, LFO, LSFO)	none	0.50%	3.1140	40.5	0.4%	31.2%
ULSFO, MDO, MGO (Ultra low- S ECA-compliant fuels with max. 0.1% S)	none	0.10%	3.2060	43.0	84.9%	24.8%
Liquefied natural gas	none	n/a	2.5364	45.1	1.3%	0.0%

As /IMO 2020/, ETW differentiates the calculation methodology by "fuel-based" and "energy-based" pollutants. The emissions of the "fuel-based" pollutants/components depend mostly on fuel quality; their base emission factors are given in g/g fuel. The fuelbased" pollutants/components covered by ETW include fuel/energy consumption, CO2 and SO_x. Emissions of the "energy-based" pollutants, on the other hand, mostly depend on the combustion processes in the engine, which are load-dependent to a large degree; their base emission factors are given in g/kWh and those covered by ETW include NO_x, NMVOC and PM.

Average emission/energy consumption factors of fuel-based components (energy consumption, CO2 and SO_x) are calculated for each IMO ship type and size class as follows:

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

With

ET

 $Sh_{FT,a}$

 Sh_{AG}

= Emission / consumption factor in g/tkm for pollutant p, machine type $EF_{p,MT,area}$ *MT* (i.e. main engine/auxiliary engine/boiler) and area type *a* (inside/outside ECA) = Area type (inside/outside ECA) а = Fuel/technology type (see Table 35) FTOA= operation area (at sea or in port) = Age group: For specific fuel consumption (i.e. engine efficiency), the AGfollowing age groups ("generations") are differentiated:

Engines built before 1983

Engines built 1984-2000

Engines built from 2001 onwards

= Engine type (for diesel engines): SSD (Slow speed diesel), MSD (medium speed diesel), and HSD (high speed diesel). Ship 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 ships are assumed to be equipped with SSD (slow-speed diesel) engines based on /Williams et al. 2008/.

= Share of fuel/technology type *FT* in area type *a* (see Table 35)

Share of ships 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 ships < 50'000 DWT and a life expectancy of up to 30 years for ships >=50'000 DWT (see also /F0EN 2015/)

= Power demand of machine type *MT* (i.e. main engine/auxiliary $W_{MT,OA}$ 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 /IMO 2020/, Table

 $EF_{p,FT,ET,MT}$

= Base emission factor for pollutant p, engine type ET, machine type MTand, in the case of PM, age group AG.

Sources:

- CO2, energy consumption: See Table 35
- SO_x: Converted from S content in Table 35 to g/g using eq. 15 in /IMO 2020/. For the fuel/technology type HFO with scrubber, we assume a reduction of 96% of SOx emissions compared to HFO use without scrubber based on /Yang et al. 2017/.

For energy-based pollutants (NOx, NMVOC and PM), average emission factors 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: Ships built before 2000
- Tier 1: Ships built 2000-2010
- Tier 2: Ships built 2011-2015
- Tier 3: Ships built from 2016 onwards

 $EF_{p,FT,ET,MT,AG}$ = Base emission factor for pollutant p, engine type ET, machine type MTand, 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/

6.3.4 Aggregation to ETW size classes and trade lanes

Depending on the input mode (Standard or Extended), different aggregation levels or fuel consumption and emission factors are required in ETW.

In the Standard mode, the user only specifies origin and destination of the cargo, as well as the cargo type (bulk or containers). Based on this, the appropriate trade lane/cargo type combination (see Table 36) is automatically chosen. Consequently, average fuel consumption and emission factors representative for the chosen trade lane are applied.

In the Extended input mode, the user can choose ship type and size, as well as the goods type and the handling (see Table 38). Hence, the fuel consumption and emission factors for the ship types and size classes available in the Extended input mode of ETW have to be available.

a) Trade lanes

For the aggregation to trade lanes, the fuel consumption and emission factors are calculated as a tkm-weighted average of the ships operating on the respective trade lane based on their size. The required input activity data (mileage, capacity, cargo utilization) are based on /IMO 2009, 2015/. Table 36 lists all region pairs considered by ETW and defines the trade lanes. The associated aggregated size classes are listed in

Table 37. The Standard mode does not differentiate liquid and dry bulk.

Table 36:	Overview of region pairs	s and respective trade lanes	considered by ETW.

From / To	EU - Europe	NA - North Am.	LA - Latin Am.	AF - Africa	AS - Asia	OZ - Oceania
EU - Europe	Intra-con- tinental Europe	Transatlantic trade	Other global trade	Other global trade	Suez trade	Other global trade
NA - North Am.	Transatlantic trade	Intra-con- tinental (non Europe)	Panama trade	Other global trade	Transpacific trade	Other global trade
LA - Latin Am.	Other global trade	Panama trade	Intracontinen tal (non Europe)	Other global trade	Other global trade	Other global trade
AF - Africa	Other global trade	Other global trade	Other global trade	Intracontinen tal (non Europe)	Other global trade	Other global trade
AS - Asia	Suez trade	Transpacific trade	Other global trade	Other global trade	Intracontinen tal (non Europe)	Other global trade
OZ - Oceania	Other global trade	Other global trade	Other global trade	Other global trade	Other global trade	Intracontinen tal (non Europe)

Vessel types	Trade lane	Aggregated size class		
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 – 7,000 (+) TEU		
CC	Transatlantic trade	2,000 – 4,700 TEU		
CC	Transpacific trade	1,000 – 7,000 (+) TEU		
CC	Panama trade	2,000 – 4,700 TEU		
CC	Other global trade	1,000 – 3,500 TEU		
CC	Intra-continental trade non EU	500 – 2,000 TEU		
CC	Intra-continental trade EU	500 – 2,000 TEU		

Table 37: Default vessel categories depending on cargo type and trade lane

Note: BC = bulk carrier, GC = general cargo ship, CC = container vessel

Great Lake BC

Average emission factors per trade lane differ due to differing size distributions per trade lane. Size differentiation can be particularly found in container trade, whereas bulk transport depends more on the type of cargo and distance sailed.

< 30,000 DWT

For container carriers, the size distribution by trade lane is updated regularly based on data from the CCWG (Clean Cargo Working Group). The major container trades are distinctive in terms of volumes and goods; therefore, different vessel sizes are deployed on those trades. For example, the Europe – Asia container trade is dominated by large container ships above 5,000 TEU. North America is linked with Asia with a broader range of vessels, usually above 3,000 TEU. In both trade lines ultra-large container vessels are used (above 14,500 TEU), too, but to a much larger extent on the Suez trade lane that the Transpacific. In the Europe – North America trades the bulk numbers of container vessels are between 2,000 and 14,500 TEU. Europe trades with the African and Latin American continent are dominated by vessels between 1,500 and 4,000 TEU capacity. For other trade lanes, average "international" intercontinental and several intra-continental emission factors are derived (see Table 36).

For bulk carriers, the ship size ranges per trade lane are based on a sample analysis of transport services of ocean carriers⁵. Size restrictions in particular regions are also considered. Some installations in the world sea infrastructure restrict the size of the vessels. The most important ones were considered in developing the vessel size classes for bulk vessels. These are the Suez Canal, the Panama Canal, and the entrance to the Baltic Sea. On the Suez Canal, bulk carriers are limited to approximately 200,000 DWT. On the Panama Canal, bulk carriers have been limited to approximately 120'000 DWT since the the opening of the canal's third set of locks, larger than the original two, in 2016. The Baltic Sea entrance is limited to bulk vessels of maximum 120,000 DWT in general. However, the ports in the Baltic Sea are mostly served by smaller feeder vessels⁶. Furthermore, the Baltic Sea as well as the North Sea are so-called Emission Control Areas (ECAs) with limits on fuel sulphur at sea and in port /Sustainable Shipping 2009/ (see Chapter 0 for the consideration of ECAs).

b) Size classes in the extended input mode of ETW

The vessel types and size classes available in the Extended input mode of ETW are listed in Table 38. The ETW vessel types are largely identical to the ship types in /IMO 2020/, but the size class boundaries differ. For this aggregation, an equal distribution of deadweight tonnage within the IMO size classes is assumed. The aggregation is carried out (as for the trade lines) by tkm-weighted averaging of all emission factors by the ETW size classes. with the input activity data (mileage, capacity, cargo utilization) based on /IMO 2009, 2015, 2020/.

The following bulk carrier schedules were analysed to develop the vessel size groupings per major trade lane: Sea bulk, Polar, AHL Shipping Company. Additionally, ship tracking websites like www.marinetraffic.com were consulted.

Personal communication, Port of Oslo.

Table 38: Vessel types and sizes that can be selected in the Extended input mode of ETW.

Vessel types (and cargo handling)	Trade and Vessel category names	Aggregated size class				
GC	Coastal	< 5,000 DWT				
BC / GC (dry)	Feeder	5,000 – 15,000 DWT				
BC / GC (dry)	Handysize	15,000 – 35,000 DWT				
BC (dry)	Handymax	35,000 – 60,000 DWT				
BC (dry)	Panamax	60,000 – 80,000 DWT				
BC (dry)	Aframax	80,000 – 120,000 DWT				
BC (dry)	Suezmax	120,000 – 200,000 DWT				
BC (liquid)	Feeder	5,000 – 15,000 DWT				
BC (liquid)	Handysize	15,000 – 35,000 DWT				
BC (liquid)	Handymax	35,000 – 60,000 DWT				
BC (liquid)	Panamax	60,000 – 80,000 DWT				
BC (liquid)	Aframax	80,000 – 120,000 DWT				
BC (liquid)	Suezmax	120,000 – 200,000 DWT				
BC (liquid)	VLCC (+)	> 200,000 DWT				
CC	Feeder	<1,000 TEU				
CC	like Handysize	1,000 – 2,000 TEU				
CC	EU SECA like Handysize	1,000 – 2,000 TEU				
CC	like Handymax	2,000 - 3,500 TEU				
CC	like Panamax	3,500 - 4,700 TEU				
CC	like Aframax	4,700 – 7,000 TEU				
CC	like Suezmax	7,000 – 14,500 TEU				
CC	ULCV	>14,500 TEU				
Global average CC	World	over all ships				
RoRo	RoRo small	< 5000 DWT				
RoRo	RoRo large	>= 5000 DWT				
(BC = bulk carrier; CC = container vessel; GC = general cargo ship; RoRo = Roll-on/roll-off ship; VLCC = very large crude carrier; ULCV = ultra-large container vessel)						

6.3.5 Adjustments for speed and cargo utilization

Ship speed is one of the most sensitive parameters in the calculation of fuel consumption and emissions of sea transport. Due to the over-proportional reduction in fuel consumption compared to the service speed, "slow steaming" has become a widespread practice in sea transport – in 2012, the average ratio of operating speed to design speed was 75% /IMO 2015/ and has since remained in this order of magnitude. Cargo utilization, on the other hand, is sensitive since ETW calculates shipment-specific emissions, and obviously these are reduced the more goods the emissions can be divided by.

In the Standard mode, the operating speed and the cargo utilization are determined by trade lane and corresponds to the tkm-weighted averages per IMO ship type and size class /IMO 2009, 2015, 2020/. In the Extended input mode, the user can adjust speed and cargo

utilization of sea transport. The speed adjustment is expressed in percent reduction relative to the chosen ship's design speed. The cargo utilization is expressed in percent of capacity.

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

a) Adjustment for speed

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 ship from the "admiralty formula" presented in Chapter 6.3.2):

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

With:

 LF_{act} = Load factor of the main engine resulting from user-defined speed settings

= Actual speed and design speed of the ship. v, v_{REF}

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 main engine, auxiliary engine and boiler, and accounts for adjustments of air pollutant emission factors for low load, as well as for the additional time at sea due to slower speed:

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

With

 EF_{adi} = Speed-adjusted fuel consumption or emission factor [g/tkm]

= Fuel consumption or emission factor of the main engine [g/tkm] EF_{M}

LAF= Low-load adjustment factor for air pollutants: Inter-/extrapolated based on factors for given load points and pollutants in Table 20, /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]

= Fuel consumption or emission factor of the auxiliary engine in port $EF_{A.Port}$ [g/tkm]

 $EF_{B.Port}$ = Fuel consumption or emission factor of the boiler in port [g/tkm]

b) Adjustment for cargo utilization

The speed-adjusted fuel consumption and emission factors are adjusted for the deviation of cargo utilization from the default using:

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

With

= Cargo utilization-adjusted final fuel consumption or emission factor EF_{final} [g/tkm]

 CU_{Def} = Default cargo utilization (/IMO 2009/, tkm-weighted average for the respective trade lane or ETW ship type and size; see Table 39) [%]

 CU_{act} = Actual cargo utilization [%]

Table 39: Default parameters used in ETW per trade lane (Standard mode) or vessel type/size class (Extended mode).

Vessel type (and cargo handling)	Trade (Standard mode) / Size class (Extended mode)	Days at sea at design speed	Design speed [km/h]	Default actual speed [km/h]	Default cargo utilization [%]	
BC (liquid, dry, general)	Suez trade	181	28.0	21.7	66%	
BC (liquid, dry, general)	Transatlantic	168	27.3	21.5	65%	
BC (liquid, dry, general)	Transpacific	171	27.5	21.5	66%	
BC (liquid, dry, general)	Panama	164	27.1	21.4	64%	
BC (liquid, dry, general)	Other global	162	27.0	21.4	65%	
BC (liquid, dry, general)	Intracontinental	145	25.5	20.4	68%	
CC	Suez	184	41.5	30.4	70%	
CC	Transatlantic	171	44.3	29.6	70%	
CC	Transpacific	173	44.3	29.9	70%	
CC	Panama	159	43.4	27.9	70%	
CC	Other global	168	43.3	29.0	70%	
CC	Intracontinental	166	42.8	28.6	70%	
CC	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%	
GC	Coastal	135	20.6	16.3	66%	
BC (dry)	Feeder	142	24.8	19.6	65%	
BC (dry)	Handysize	145	26.2	21.0	64%	
BC (dry)	Handymax	149	26.8	21.4	64%	
BC (dry)	Panamax	168	26.9	21.3	64%	
BC (dry)	Aframax	174	27.0	21.2	66%	
BC (dry)	Suezmax	190	27.1	21.0	70%	
BC (liquid)	Feeder	151	25.4	20.7	73%	
BC (liquid)	Handysize	156	26.6	21.7	75%	
BC (liquid)	Handymax	155	27.4	22.2	69%	
BC (liquid)	Panamax	167	27.6	22.5	77%	
BC (liquid)	Aframax	161	27.9	22.0	71%	
BC (liquid)	Suezmax	177	29.4	23.0	71%	
BC (liquid)	VLCC (+)	187	28.5	22.3	65%	
CC	Feeder	145	29.6	21.9	70%	
CC	like Handysize	148	35.2	24.8	70%	
CC	like Handymax	151	40.4	26.6	70%	
CC	like Panamax	157	42.8	27.2	70%	
CC	like Aframax	163	45.1	28.8	70%	
CC	like Suezmax	174	44.4	30.1	70%	
CC	ULCV	204	37.4	30.6	70%	
CC	Global average	168	42.3	28.9	70%	
RoRo	RoRo small	93	20.7	15.0	70%	
RoRo	RoRo large	168	34.8	27.7	70%	
All ship types	Global average	174	30.5	23.4	67%	

6.3.6 Consideration of emission control areas (ECAs)

Emissions from sea 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 applies only to ships constructed after that date, while for SO_x and PM, all ships must comply from the date of entry into effect. This difference is due to the fact that SO_x and PM emissions mainly depend on the S content of the fuel, which can be switched on an existing ship, while for the reduction of NO_x emissions, a new or upgraded engine is required.

Existing Emission Control Areas include⁷:

- 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 (SOx, and PM in effect from 2012, NO_x from 2016).
- US Caribbean ECA, including Puerto Rico and the US Virgin Islands (SOx, and PM in effect from 2014, NO_x from 2016).

The fuel sulphur limits inside and outside ECAs are depicted in Figure 16.

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 35). Other options are to use a scrubber, an aftertreatment technology that uses sea water to wash SO₂ out of the exhaust gas, or to switch to LNG instead of diesel. However, the latter two options are less widespread: as of 2020, approximately 14% of container ships were fitted with scrubbers /ICCT 2021/ and about 1.3% of energy use in ECAs was accounted for by LNG (analysis of CCWG data).

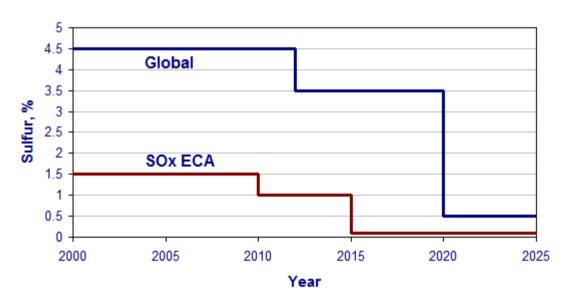
ETW accounts for the impact of ECAs on emissions by using the respective fuel mixes inside/outside ECAs (Table 35) to weigh base emission factors (see Chapter 6.3.3).

⁷ https://www.imo.org/en/OurWork/Environment/Pages/Special-Areas-Marpol.aspx

Besides ECAs, stricter emission limits also apply to certain ports, e.g. 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. As a simplified assumption, ULSFO or MGO/MDO (with max. 0.1% sulphur content) is assumed to be used in ports with stricter emission limits or voluntary fuel switch programs, i.e.:

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

Figure 16 MARPOL Annex VI fuel sulphur limits (source: Dieselnet 2015).



6.3.7 Allocation rules for seaborne transport

The emissions of ocean-going vessels are averaged over the entire return journeys, taking the load factors and empty returns into account. All emissions are allocated to the freight carried.

For bulk vessels the allocation unit is tonne-kilometre (tkm). All emissions are allocated to the product of transported tonnes of freight and distance travelled. The emissions of container vessels are calculated on a container-kilometre basis (TEU-km). tkm and TEUkm are converted to each other using the container weights presented in Table 9 for volume, average and bulk goods.

6.3.8 Ferry transport

Ferry transport is a special case within ETW as it represents a "hybrid" mode of transport, i.e. it is road or rail transport on a ship. ETW handles ferry routes as an extension of the road and rail network. The user of the web interface cannot choose "ferry" as a mode, but ferry transport is chosen automatically when the mode is road or rail and the most advantageous route leads via a ferry route (compare Chapter 5.2). In the extended mode, the user can choose whether to explicitly avoid or prefer ferry routes. 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 (see chapter 6.3).

The allocation of the energy consumption between passenger and goods transport is a tricky and controversial issue. Different allocation methodologies have been proposed (e.g. /Kristensen 2000/ or /Kusche 2000/); the decision which is the most appropriate cannot be made objectively but remains a convention. In conformity with the European norm (EN) 16258, ETW allocates the energy consumption to freight according to the share of deck area dedicated to vehicles.

The final 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:

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

All input parameters for this equation have been derived based on two studies from the Baltic and Mediterranean Seas, i.e. /Scandria 2012/ and /Holmegaard and Hagemeister 2011/. Their values are displayed in Table 40.

Table 40: Parameters for the calculation of final fuel consumption of cargo on ferries.

Parameter	meter Description		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%
СС	Cargo capacity of the ferry [t]	t	5,218
CU	Cargo capacity utilization of the ferry	%	64%

The fuel consumption per net tonne-kilometre (i.e. allocated only to the weight of goods transported inside the train or truck) is calculated by dividing the fuel consumption per gross tonne-kilometre by the ratio of the weight of the goods transported to the weight of the vehicle including the goods transported (compare Chapters 6.1 and 0):

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

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

The same pollutant emission factors in g/g fuel have based on /IMO 2015/ are used as for other sea transport (see chapter 6.3.3), assuming a share of 65% of the main engine in total fuel consumption (based on /IMO 2015/).

Inland waterway transport 6.4

6.4.1 Overview

The methodology for inland waterway transport has been updated compared to previous versions of ETW (see /ifeu, INFRAS, IVE 2014/). The main focus was to consider up to date fuel consumption and emission factors data and update ETW where necessary.

Inland vessels are modelled in a bottom-up approach similar to ocean-going vessels (see Chapter 6.3). However, instead of applying tkm-weighted average fuel consumption and emission factors for aggregate ETW classes, four representative ship types are provided:

The Europa ship, representative for ships with up to 1500 t capacity, and used by default on rivers of CEMT Classes I-IV8;

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 /CEMT 1992/. The standard specifies the maximum measures (length, bean, draught, tonnage) for ships to be able to navigate on rivers of each class.

- The "Grossmotorschiff", representative for ships with 1500 3000 t capacity, and used by default on rivers of Class V;
- The Jowi class, representative for capacities >3000 t, used by default on rivers of Class VI.
- A 2x2 push convoy (Push boat and 2x2 "Europa" barges) with a capacity of 11'200 t, representative for convoys and selectable on rivers of class V and above.

This approach is more appropriate given the lack of activity data on inland navigation (especially outside Europe), which would have added uncertainty to any tkm-weighted aggregation. For Europe, a comparison of mean fuel consumption factors with tkmweighted aggregated classes has shown that the three ship types listed above represent their size classes well. World-wide, a comparison of EcoTransIT 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 CO2 emission factors by ship 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.

The resulting fuel consumption and emission factors are further adjusted to a default or user-specified cargo utilization.

6.4.2 Inland waterways in ETW

The majority of waterways available in ETW are located in Europea. All European waterways class IV and above are included in ETW (Figure 17). Most prominent are the rivers Danube, Elbe, Rhine, and Seine⁹, 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.

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

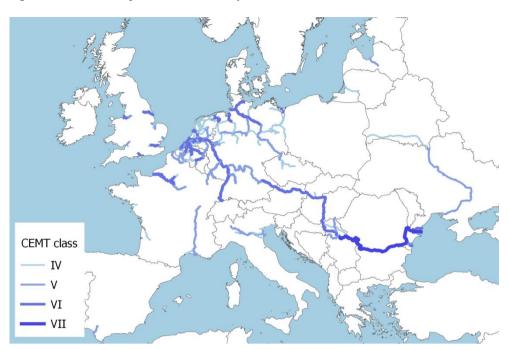
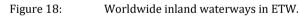
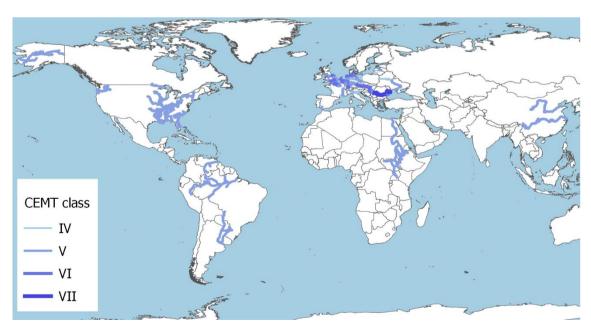


Figure 17: European inland waterways and their classification

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 exhibit significant inland waterway transport performance /Amos et al. 2009/. ETW enables inland waterways calculation on the largest global waterways, such as the Yangtze, Mississippi or Amazon rivers. The CEMT classification is not available on non-European waterways; therefore, the class V is assigned per default to all waterways outside Europe (Figure 18).





6.4.3 Derivation of basic fuel consumption and emission factors

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

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

$$FC_M = ((P \times LF_{CU})/V)/(CU \times Cap) \times SFC$$

With FC_M = Fuel consumption of the main engine [g/tkm or g/TEU-km]

P =Installed power [kW] /Panteia 2013/

 $LF_{CII} =$ 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 ships based on /ifeu and INFRAS 2013/)

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 ship 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 /ifeu and INFRAS 2013, BMVBS 2011/:

$$LF_{CU} = LF_{emptv} + (LF_{full} - LF_{emptv}) \times CU$$

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/.

Technical data on the three inland barge types provided in ETW are listed in Table 41.

Table 41	Inland vessel technical	parameters

	Default for	Length	Beam	Installed	Average	Capacity		Default cargo utilization	
Vessel type	CEMT river class	[m]	[m]	power [kW]	speed [km/h]	DWT (bulk)	TEU (Con- tainer)	Bulk	Con- tainer
Europa ship	I - IV	85	9.5	737	10.5	1'350	100	60%	60%
Great Engine Vessel	V	110	11.4	1'178	10.5	2'500	200	50%	60%
JOWI class	VI+	135	17.34	2'097	10.5	5'300	450	50%	60%
2x2 push convoy	selectable on VIb+	195	22.8	3'264	10.5	11'200	820	50%	60%

The emission factors for inland vessels have been updated compared to /ifeu, INFRAS, IVE 2014/). Similar to 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. This fact should be considered in ETW by providing different emission factors by emissions stage, like already available for road transport.

Table 42 lists the emission levels and emission factors available for ETW. The factors for the emission stages "conventional", "CCNR I" and "CCNR II" were derived from type approval data and literature data for European ships, see /ifeu and INFRAS 2013/. Emission factors for EU V are based on an analysis by TNO /Ligterink et al. 2019/. The emission limits for the EU V stage vary depending on the engine power class. For EcoTransiT, a ratio of 35% of ships with engines <300 kW and 65% >300 kW was assumed for simplification, based on data for Germany in the TREMOD model /Heidt et al. 2016/. 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 202115/.

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 42 Inland vessel engine emission factors in gram per kWh (engine power)

Emission stage (manufacture year)	NOx (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			
EU V (2022+) engine power <300 kW	3,15	0,37	0,11			
EU V (2022+) engine power >=300 kW	2,93	0,24	0,02			
US Tier 3	5,44	0,24	0,14			
US Tier 4	2,31	0,06	0,03			
Source: /ifeu and INFRAS 2013/, /TNO 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 /Heidt et al. 2016/. The default setting in the EcoTransIT 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, 2021/. 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 ship or engine age.

6.4.4 Allocation rules for inland waterway transport

For inland waterway navigation, the same allocation rules as for ocean transport apply (see Chapter 6.3.7).

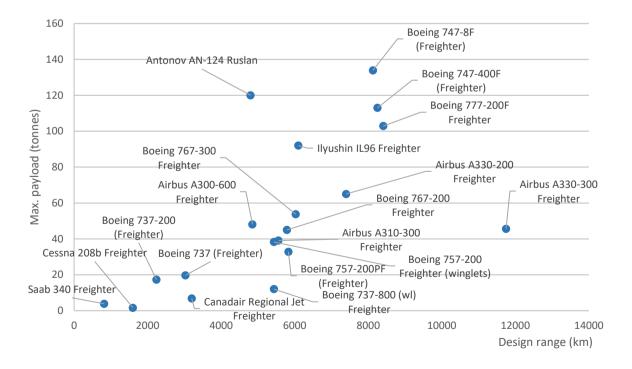
6.5 Air transport

6.5.1 Type of airplanes and load factor

The type and model of airplanes (e.g. Boeing 747-400, B777F) used for air cargo has a high impact on GHG emissions and air pollutants. On the one hand the type gives the information about the capacity of the airplane and age of the turbine used. On the other hand, the aircraft type delivers information if air cargo is transported in dedicated freighters (only for freight) or together with passengers in aircrafts (so-called belly freight). This information is important for the allocation methodology (see subchapter 6.5.4). In the extended input mode of ETW 42 dedicated freighter and some 200 passenger aircraft types are available for selection. For the full list of aircraft type refer to the table the appendix 7.2.

Each aircraft is characterised by both a maximum possible design range and a maximum payload (maximum freight weight). Large passenger aircrafts such as the Boeing 777-200LR or the Airbus 340-500 and 350 can fly without stopovers more than 15,000 km. The longest range today is achieved by the Airbus 350-900ULR of Singapore Airlines / Simplyflying 2022 /. Longer range, however, comes at the price of less passenger and / or freight capacity. For example, Singapore Airlines' Airbus 350-900 offers 303 seats in the medium haul version, 253 seats in the long-haul version (range: 15'372 km) and only 161 seats in the ultra-long haul version (range 17'965 km) / Singapore Airlines 2022; Airbus 2022/. Obviously, larger aircrafts can transport more freight than smaller ones. The maximum payload capacity of larger aircrafts is much higher. ETW includes a wide range of small, medium and large aircrafts covering the whole possible spectrum of operating distances and payloads, which is shown exemplarily for selected freighter aircraft in Figure 19. ETW considers only the so-called design range of the aircrafts, which is the maximum range for the case if the whole structural payload is utilised /Hünecke 2008/. Beyond this range the payload has to be reduced due to the additional fuel needed for the longer flight. This possibility is not considered by ETW.

Figure 19 Design ranges and maximum payload capacities of selected dedicated air freighters



Within the extended input mode ETW provides only aircrafts suitable for the flight distance between the selected airport pair. If the trip distance is longer only those aircrafts are offered by ETW that are able to fly this distance. The longer the flight, the

fewer the types of aircrafts provided (see Figure 19). Additionally, the aircraft are distinguished between dedicated freighter and passenger aircrafts. The characteristics of all freighter and passenger aircrafts included in EcoTransIT are available in Table 63 in the annex.

In the standard input mode of ETW, an own selection of airplanes is not possible. Rather, ETW use the airplanes of Table 43 depending on the flight distance (up to 1,000 km short haul aircraft; over 1,000 km up to 3,700 km medium haul aircraft; more than 3,700 km long haul aircraft). Because to the users of the standard input mode it is usually unknown whether a dedicated freighter or passenger aircraft is used, ETW uses a mix of both aircraft types. This mixed aircraft type is called "hybrid aircraft". Before the Covid pandemic, between 40% and 53% of freight ton-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 /Knowler 2022/ again. This values 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. For the hybrid aircrafts of EcoTransIT, independent of flight distance, a share of 40% belly freight is used. It is likely that this value will rise in or after 2024. Thus, if a user of the standard input mode selects airports EcoTransIT calculates firstly the distance of the flight (e.g. 5,200 km). In the next step EcoTransIT identifies the freighter and the passenger aircrafts fitting to the flight distance (in this case Boeing 747-400F and Boeing 747-400). In the last step energy consumption and emissions are calculated for both aircraft types and mixed by the share 60% freighter and 40% belly freight. In the standard mode EcoTransIT shows only the mixed result of this hybrid aircraft.

Table 43 Characteristics of selected aircrafts

Туре	Distance Group	Type of aircraft	IATA Aircraft code	Design Range (km)	Max. Payload (t)	Typical Seats (number)
Freighter	Short haul	Boeing 737-300SF	73Y	3,030	19.7	
Freighter	Medium Haul	Boeing 767-200F	76X	5,790	45.0	
Freighter	Long haul	Boeing 747-400F	74Y	8,250	113.0	
Belly Freight	Short haul	Embraer 190	E90	3,330	1.4	98
Belly Freight	Medium Haul	Airbus 320	320	5,700	2.4	150
Belly Freight	Long haul	Boeing 747-400	744	13,450	16.8	416
Sources: Lang	2007; Lang 2009;	LCAG 2014.				

Mainly high value volume or perishable goods are shipped by air freight and the permissible maximum weight is limited. Therefore, only the category volume goods are included within the ETW tool – independent of using standard or extended input mode. Other types of goods (bulk, average) are not available for air cargo. The load factors used for volume goods differentiated by short, medium and long haul are contained in chapter 4.2.3.

6.5.2 Energy consumption and emission factors (Tank-to-Wheel)

Specific TTW energy consumption and TTW emissions of air cargo transportation depend heavily on the length of the flight. This is caused by different energy needs and emissions in different phases of flight (e.g. take-off or climb). Due to the data sources used by ETW this dependency from flight distance is considered for air pollutants like NOx, NMHC and PM. For fuel consumption the data source used (EUROCONTROL "Small Emitters Tool", see below) only considers a linear correlation between energy consumption and flight distance. This simplification is legitimate since most air cargo flights are long haul flights where take-off and landing phases don't dominate the overall energy consumption of the whole flight. Furthermore, energy consumption and emissions depend on utilisation of the capacity of aircrafts (utilisation of payload capacity). Whereas this dependency is considered by road transport, this was not able for aircrafts due to lack of available data. But the possible error is small and therefore iustifiable.

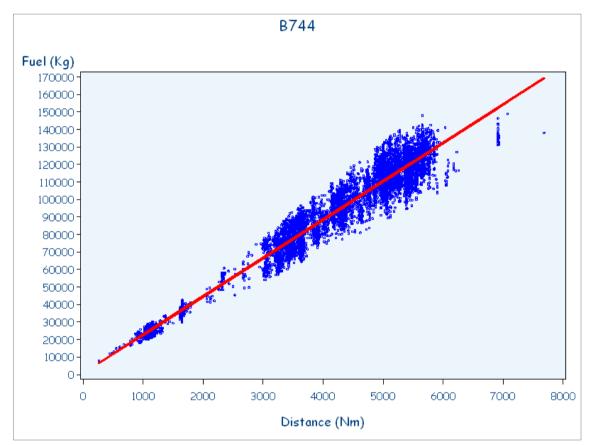
The basis of fuel consumption for the different airplanes considered by ETW is the EUROCONTROL "Small Emitters Tool" 10 which has been developed on behalf of the European Commission for reporting under the European Emissions Trading Scheme (ETS) /EUROCONTROL 2009,2015, 2017, 2019 and 2021/. This data source is updated yearly and covers a wide range of aircrafts and aircraft families including many newer ones /BEIS 2016/. The Small Emitters Tool covers more than 400 different aircraft types including turboprop engines. EUROCONTROL gathers, on a regular basis and from volunteer aircraft operators in Europe, samples of actual fuel-burn data for their flights performed in a specific year. Based on this fuel-burn data a linear regression is carried out for each aircraft type in the sample to consider the fuel dependency from distance flown (see for example in Figure 20) /EUROCONTROL 2009/. In total measured energy consumptions are available for 109 different aircraft types in the Small Emitters Tool.

In a second step the Small Emitters Tool uses conclusions by analogy for aircraft families. That means that for aircrafts without measured fuel-burn data the energy consumption of other aircraft types of the same family is used (e.g. fuel-burn data from B747-400 for B747-300). In these cases, the measured data are adjusted by using a correction factor based on the MTOW (maximum take-off weight) ratio /EUROCONTROL 2009/. This approach is used for around 40 airplanes. In a third step data from the EMEP/EEA Air

¹⁰ See also http://www.eurocontrol.int/small-emitters-tool.

Pollutant Emission Inventory Guidebook (formerly called the EMEP CORINAIR Emission Inventory Guidebook) is used for around 30 airplanes /EEA 2013, 2015 and 2019/. Last but not least for the remaining aircraft types (around 290) the average fuel consumption per flight kilometre is calculated based on linear regression model based on the available data considering the MTOW of each airplane /EUROCONTROL 2009/.

TTW energy consumption of the Small Emitters Tool is based on a linear Figure 20 regression of fuel-burn data collected in Europe - example of a Boeing 747-400 /EUROCONTROL 2009/



Since the Small Emitters Tool contains only fuel-burn data for one aircraft model (e.g. Boeing 747-400), the data is used for both dedicated freighter and passenger aircrafts (see Table 44: Boeing 747-400F). Most of the energy consumption data of the 144 freighter and passenger aircrafts considered in ETW are based on measured fuel-burn data collected in context of the Small Emitters Tool. For about 20 aircrafts conclusions by analogy from other family models are used. For 35. Table 44 shows exemplarily the TTW energy consumptions for the six airplanes used for calculation of the "hybrid aircrafts" in the standard input mode of ETW relating to discrete travel distances. These energy consumption values are completely based on measured fuel-burn data from the Small Emitter Tool. For distances between the discrete mission distances given in Table

44 (e.g. between 4,630 and 5,556 km) the fuel consumptions of the aircrafts are calculated by linear interpolation.

Table 44 TTW fuel consumption of selected freighter and passenger aircrafts depending on flight distances

	De	dicated freigh	ter	Passenger aircrafts			
Distance (km)	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	

CO₂, CO₂ equivalents and SO_x depend directly on the amount of kerosene consumed by the airplanes. For CO₂-equivalent the emission factors of the ISO 14083 are used without changes. The CO₂ emission factor used by ETW is based on the same sources than the CO₂ equivalent emission factor included in the ISO so that the CO₂ emissions calculation of ETW is comparable with the approach of ISO 14083*. For SO_x an emission factor of 0.84 g per kg kerosene is applied for ETW /EEA 2013/2015/. This value is based on data from EUROCONTROL. On national level the values can be much lower. For example, in Germany an emission factor of 0.4 g SO₂ per kg kerosene in 1998 and 0.2 g SO₂ per kg kerosene in 2009 is used /Öko-Institut 2010; ifeu and Öko-Institut 2012/.

Table 45: Fuel-based emission factors for CO₂, CO₂e and SO_x (TTW) for kerosene (jet A and jet A1)

	g/kg fuel				
Carbon dioxide (CO ₂)	3.15				
Carbon dioxide equivalents (CO _{2e})	3.18				
Sulphur dioxide emissions (SO _x)	0.84				
Sources: EEA 2013/2015; EN DIN 2012; Öko-Institut 2010.					

NO_x, NMHC and PM are air pollutants which are independent from the fuel consumption of the aircrafts. For these air pollutants ETW uses emission factors of the EMEP/EEA Air Pollutant Emission Inventory Guidebook /EEA 2013/2015/. This guidebook provides detailed emission factors for NO_x, HC and PM of around 75 different aircraft types with regard to 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 has to be taken into account 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 aircrafts calculated for a concrete city pair /ICAO 2012/. Nevertheless, EMEP/EEA data is the most comprehensive publicly available data source for NOx, HC and PM emissions of aircrafts.

For ETW the emission data of the EMEP/EEA Guidebook are used directly without changes /EEA 2013/2015/. Table 46 shows the results for the aircraft type Boeing 747-400 according to the flight distance. Since the emission values are also given only for discrete mission distances, emissions for flight distances between those listed in the Table 46 are calculated by linear interpolation. In some cases, the data from the EMEP/EEA Guidebook doesn't cover the maximum ranges of the airplanes. For these cases the emission values were extrapolated to cover the whole ranges needed for the ETW calculations. These extrapolation steps were done by using a polynomial regression. Because the EMEP/EEA Guidebook only includes distance related emission factors for hydrocarbons in total (HC), NMHC emissions have to be calculated afterwards. Therefore, it was assumed that the NMHC emissions for the Landing and Take-Off cycle (so-called LTO cycle, <1,000 m altitude) be 90% of total HC emissions, while during cruise only NMHC is emitted /EEA 2013/2015/. The NMHC values in Table 46 consider already this adjustment step.

 NO_X Distance **NMHC** PM (km) (kg) (kg) (kg) 232 105 2.70 0.49 3.18 0.76 463 149 1.24 926 207 3.78 1,389 4.34 1.79 268 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

14.65

15.48

16.51

17.77

12.92

13.84

14.94

16.21

1617

1767

1886

1992

Sources: EEA 2013/2015; INFRAS calculations.

Table 46 NOx, HMHC and PM emissions of aircraft type Boeing 747-400 (freighter)

6.5.3 Emission Weighting Factor (EWF)

1,112

12,038

12,964

13,890

Some air pollutants (in particular nitrogen oxides, ozone, water, soot, sulphur) emitted by aircrafts in cruising altitude can have an additional climate impact to CO₂ /IPCC 1999, Lee et al 2020/. To express these additional climate impact very often the so called "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. That means that the total climate impact of the emissions of airplanes is twice the impact of TTW CO₂ emissions / Lee et al 2020/.

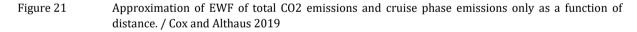
Disadvantage of the RFI is, that this factor considers only the present radiative forcing of air pollutants and water vapour. This factor is inapplicable to calculate CO₂ equivalent emissions, because this indicator takes into account the global warming potential (GWP) of emissions measured over a time 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 CO₂ over a time period of 100 years /Graßl and Brockhagen 2007/.

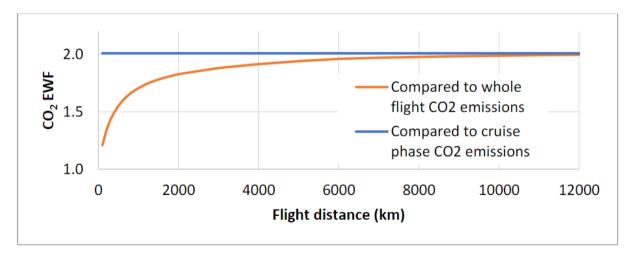
EWF is also applied for cruising in an altitude over 9 kilometres and lies between 1.3 and 3.6 / Cox & Althaus 2019 /. For ETW the user can choose to consider the EWF for the calculation of the CO₂ equivalent emissions. In this case an average EWF of 2.0 for flights over 9 kilometres above sea level is used based on Cox & Althaus 2019/11. The average EWF for the entire flight including take-off and landing is shown in Figure 21 according to the total flight distance. The EWF value is approximated using the logarithmic fit function and applying a cap value of 2.0:

EWF = min(2.0, 0.1612 * ln(distance) + 0.5534)

This function was derived for EcoTransIT based on Cox & 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 has to be pointed out that considering EWF (or RFI) for the calculation of CO₂ equivalent emissions of air traffic is not compliant with the European standard EN 16258*. That means that results are only fully in accordance with EN 16258* without considering EWF for calculation of CO₂ equivalent emissions. This is the reason EWF gives the user the possibility to additionally select EWF on their own responsibility. In this case the user cannot state that the results are in line with EN 16258*. For this reason, the factor can only be calculated via the interfaces of the Business Solutions.



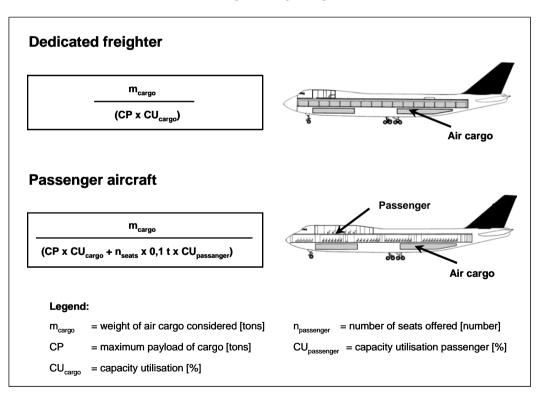


¹¹ In this case the TTW CO₂ equivalent emissions are calculated by multiplication of the TTW CO₂ emissions with the factor 2.0

6.5.4 Allocation method for belly freight

The energy consumption and emissions of dedicated freighters are simply allocated per leg (airport pair) by using the quotient of air cargo weight considered and the total payload within the aircraft. The latter is the product of maximum payload capacity (CP) and the capacity utilisation (CU). For belly freight the energy consumption has to be split between air cargo and passenger. For the allocation of emissions between passenger and freight different approaches are principally possible /EN 16258*; ICAO 2012/. ETW uses the approach used (and required) by the European Standard EN 16258*. In accordance with EN 16258* a weight of 100 kg (= 0.1 t) per passenger is assumed. Figure 22 contains the concrete formula to allocate the energy consumption and emissions of passenger aircrafts.

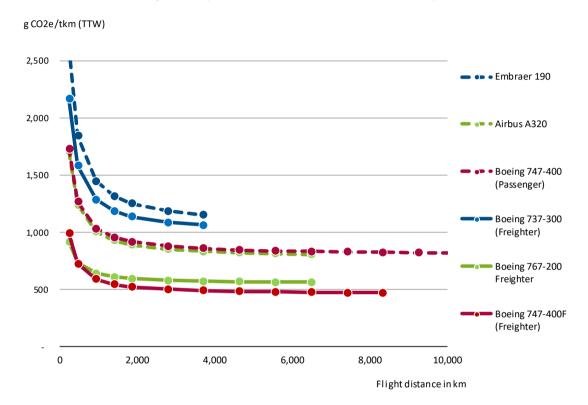
Figure 22 Allocation rules for dedicated freighter and passenger aircrafts in accordance with EN 16258



The approach required by EN 16258*, which is used for belly freight, leads to higher fuel consumption and emissions of air cargo carried by passenger aircrafts compared to that of freighters. As Figure 23 shows, for aircrafts used for the standard input mode of ETW, the CO₂ emissions of belly cargo is 20 to 80% higher as air cargo transported by dedicated freighters. Additionally, the figure shows that the specific CO₂ emissions of smaller aircrafts (e.g. B737-300SF) are much higher than those of larger aircrafts which

are used for long-haul flights (e.g. B 747-400F). In this context it has to be noted, that small aircrafts are only used for short-haul trips up to 1.000 km, medium sized aircrafts for medium-haul trips between 1.000 and 3.700 km, while big aircrafts are only used for long-haul flights over 3.700 km within ETW.

Specific TTW CO₂ emissions of selected freighter and passenger aircrafts in g/tkm used for the ETW Figure 23 standard input mode /EUROCONTROL 2017; INFRAS calculations/



6.6 Emission factors for different fuels

Additional to the operational emissions (also called Tank-to-wheels/ TTW) caused directly by operating the vehicles; the total emissions (also called Well-to-Wheels/WTW) which include the emissions from the generation of the final energy (Well-to-tank/WTT) are taken into account by ETW. Thus the impacts of extraction and generation of the different energy carriers are also included. Considering total as well as operational GHG emissions is a requirement of the international standard ISO 14083. ETW provides operational as well as total emission data not only for energy consumption and GHG emissions, but also for all air pollutants. Therefore, ETW provides emission data always in the same system boundaries required by ISO 14083.

The main energy carriers used in freight transport processes are liquid fossil fuels such as diesel fuel, kerosene, heavy fuel oil and electricity. 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 entrance of the power plant
- Conversion within the power plant (including construction and disposal of power stations)
- Energy distribution (transforming and catenary losses)

Energy chain of fuel production:

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

These system boundaries are in line with the new ISO 14083 norm.

Since the ISO 14083 distinguished between European fuel emission factors and US fuel emission factors, EcoTransIT World factors are grouped into two country groups: US/ Canada and Europe. The European factors are also used for the rest of the world where reliable fuel emission factors are currently missing.

6.6.1 Emission factors of fossil fuels in Europe

The new ISO 14083 covers emission factors for fossil fuels used in Europe in its appendix. Here, density values, lower heating values and operational (also called TTW) GHG emissions as well as total (also called WTW) GHG emissions are given. For ETW, we needed to supplement these factors with other values like fossil CO₂ emissions, energy use (EC) as well as several air pollutant emissions.

Whenever possible, the additional values come from the same primary source(s) as the GHG emission values given in ISO 14083. However, the JEC WTW study v.5 does not cover air pollutant emissions, therefore we have calculated the NO_x, NMHC, SO₂ and PM10 WTT values for CNG, LNG and H₂ SMR using our own ifeu model for fossil fuel pre-chains.

The resulting fuel properties, GHG and fossil CO₂ emission values are shown in Table 45.

This table also includes three additional fuel types not covered by ISO 14083: low sulphur fuel oil, very low sulphur fuel oil and ultra-low sulphur fuel oil.

Table 47 Fuel properties and GHG emission factors for fossil fuels and gases (ISO 14083) + fossil CO2 emissions

	density (d)	Lower heating value	CO2e-fac	tor	CO2-factor	
		MJ/kg	gCO₂e/MJ		gCO2/MJ	
Fuel type description	kg/l	operational	operational	total	operational	total
Gasoline	0.743	42.5	75.1	90.1	74.8	88.5
Diesel	0.832	42.8	74.1	87.3	74.1	86.0
Liquefied Petroleum Gas (LPG)	0.55	45.5	67.1	81.6	66.7	80.0
Compressed Natural Gas (CNG)*	Х	49.2	56.6	72.7	55.1	65.2
Kerosene	8.0	43.0	73.5	84.7	73.4	83.5
Heavy Fuel Oil (HFO) (2.5% sulphur)	0.97	42.6	76.8	85.4	75.7	83.3
Liquefied natural gas (LNG)*	Х	49.1	57.9	75.5	56.4	67.2
Hydrogen (from SMR)	Х	120	0	114.4	0	105.0
Low sulfur fuel oil (LSFO) (1% sulfur)	0.975	41.1	78.7	95.8	77.6	92.5
Very low sulfur fuel oil (VLSFO) (0.5% sulfur)	0.975	41.3	78.7	96.7	77.7	93.3
Ultra low sulfur fuel oil (ULSFO (0.1% sulfur)	0.930	41.1	78.6	96.6	77.5	93.3
*only valid for SI trucks, values for other vehicle	es and engine	types are differen	t due to methan	e slip.		

Sources: ISO 14083, ecoinvent v. 3.8 (cut-off), JEC WTW study v.5 as well as ifeu calculations

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

Fuel	EC	NOx	SO ₂	NMHC	PM
	MJ/MJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Gasoline	0.284	50.1	107.4	40.1	7.5
Diesel	0.327	47.6	92.5	29.0	7.0
LPG	1.300	68.9	108.3	40.5	8.4
Kerosene	0.249	45.1	81.9	27.6	6.3
Heavy fuel oil	0.181	39.8	63.8	25.7	5.2
CNG	0.227	35.2	92.6	17.3	5.5
LNG	0.180	39.7	97.0	18.2	6.0
H2 SMR	1.053	52.5	125.7	23.0	7.5
LSFO	0.253	35.6	150.2	37.6	6.4
VLSFO	0.269	36.4	152.9	37.9	6.5
ULSFO	0.225	36.4	153.1	36.9	6.6

Table 48 Emission factors for energy production of liquid and gaseous fuels (WTT)

Sources: ecoinvent v. 3.8 (cut-off) for gasoline, diesel, LPG, kerosene, HFO as well JEC WTW study v.5 for CNG, LNG and H2 SMR (EC values, other values from ifeu calculations)

6.6.2 Emission factors for low sulphur sea ship fuels in Europe

The emission factors for the marine fuels low sulphur fuel oil (LSFO), very low sulphur fuel oil (VLSFO) and ultra-low sulphur fuel oil (ULSFO) are essentially determined by the two steps of crude oil supply and processing in the refinery.

Crude oil supply

The crude oil supply data for marine fuels are based on information compiled by ESU 2021 for Europe (Bussa et al. 2021; Meili et al. 2021). These include current data on energy consumption and on import routes. In the present calculation results for ETW, the information on increased methane emissions along the production chain (IEA 2020; Jackson et al. 2020; Saunois et al. 2020) is excluded in order to remain consistent with the other fuel supply chains of ETW. However, future updates of ETW should take into account real methane emissions for all fuels from oil and gas. In the current version 3.9.1 (from December 2022) of the renowned life cycle assessment database ecoinvent, the amendment has already been made.

The import mix used for the crude oil supply is shown in Table 49.

Table 49 Country supply mix for crude oil

Country	Importmix
Azerbaijan	3,3%
Canada	0,1%
Germany	2,2%
United Kingdom	11,6%
Iraq	3,1%
Kazakhstan	7,2%
Mexico	0,9%
Nigeria	6,9%
Netherlands	1,4%
Norway	11,0%
Russian Federation	30,8%
Saudi Arabia	2,6%
United States	6,1%
Libyan Arab Jamahiriya	9,5%
Algeria	3,3%

Sources: ESU (Meili et al. 2021)

Refinery

The ifeu refinery model has been developed at the end of the nineties of the last century, when consistent LCI 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 (BREF 2015). Further specific data was collected from companies and production plants and was incorporated in order 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 age as well as environmental regulations can result in a wide variety of refinery concepts. These specifications define the requirements for the ifeu model.

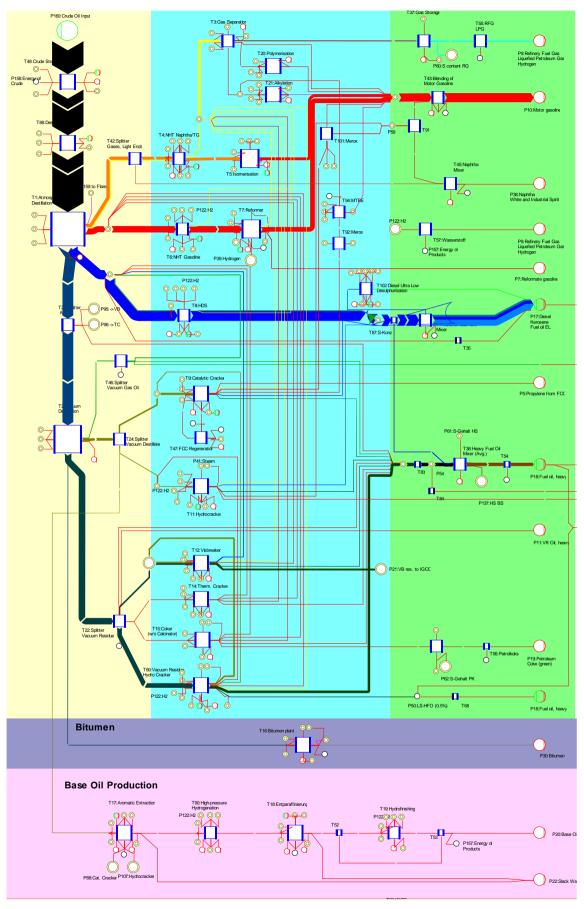


Figure 24: Screenshot of the ifeu petroleum refinery model in UMBERTO

Figure 24 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 (section 1.3.3) and Eurostat-data, taking into account 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, the Eurostat and the European Pollutant Release Transfer Register (E-PRTR, https://ec.europa.eu/environment/industry/stationary/e-prtr/legislation.htm).

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 - could not 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 presettings described above, driven by "common sense" and is in line with the ISO 14044 guidelines on life cycle assessment.

Four rules of allocation

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: the majority of 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 exactly the non-intended bottom products (e.g. vacuum residue, cracking residue; see box 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 within that box).

Rationale: all these downstream processes within the refinery are intended to reduce non-intended products in favour to increase the yield of the majorly intended coproducts; 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 rule 3 and 4 heavy fuel oil would turn out to be the product with the highest back pack, which would contradict any value-based perception of the refining business.

Further information on the ifeu refinery can also be found in the LCA database ecoinvent (https://ecoinvent.org), which uses results from the ifeu refinery model for its fuel LCI calculation (ifeu 2018).

The refinery's specific model parameters for the low-sulphur marine fuels were determined within the context of the EU JOULES project (https://joulesproject.eu/Joules/). 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 VLSHFO; the effects of higherquality feed and lower hydrogen demand partially cancel each other and lead to similar results.

The resulting WTT emission factors for the marine fuels are shown in Table 50.

Table 50 WTT GHG emissions of marine fuels from crude oil supply and refinery processes

	Crude Oil	Refinery gCO₂e/MJ	Total
Low sulfur fuel oil (LSFO) (1% sulfur)	11.7	5.2	16.8
Very low sulfur fuel oil (VLSFO) (0.5% sulfur)	11.8	5.8	17.6
Ultra low sulfur fuel oil (ULSFO (0.1% sulfur)	11.1	6.2	17.3

Sources: ifeu calculations

6.6.3 Emission factors of biogenic fuels in Europe

Previously, biodiesel and ethanol emission factors were taken from the EN 16258. However, this norm is fairly old, and it's biofuel emission factors were still based on the first renewable energy directive. With the recast of the renewable energy directive (RED II) from 2018 the needed GHG reductions to count towards the biofuel quota were raised to 65-70%. Therefore, an update of the biofuel emissions in EcoTransIT World was needed. This update further introduces new biofuel types not covered by the EN 16258: compressed biomethane (Bio CNG), liquefied biomethane (Bio LNG) and hydrotreated vegetable oil (HVO).

Scope and generic approach

The updated emission factors for greenhouse gas emissions and non-GHG pollutants were compiled consistently. The tool used for this was created as part of the BioEm project (Fehrenbach et al. 2016) and adapted for the purposes here in the data bases. It includes direct and upstream emissions from cultivation, processing and transport of raw materials, intermediate products and biofuels to the filling station. The BioEm tool enables also the inclusion of emissions from land-use change. However, this was excluded for the emission factors determined here. The reason for this is the lack of consensus among experts on an agreed methodological approach. This would have to be revised for future updates, as factors for land-use change have been recently published with the CORSIA emission factors (ICAO 2021). Thus, such factors now enter into general use.

The calculation method closely follows the methodological rules of the RED and RED II. This means in particular the handling of co-products, which are considered through allocation according to the lower calorific value. In principle, no offsets and credits are assigned when calculating the emission factors. This concerns components that are also mentioned in the RED and have partly already been considered in the calculation of actual values. Specifically, it concerns credits for the use of captured CO₂ (CCR or CCU), for soil carbon accumulation via improved agricultural management or the avoidance of methane emissions through the fermentation of manure into biogas or biomethane.

Basic assumptions for the update

There are numerous data sources for emission factors for biofuels. Why a separate derivation here? In fact, there is currently no database that both reflects as current a situation as possible and at the same time includes factors for both GHG and non-GHG emissions consistently. The authors have been working on this issue for years and have a good assessment of how the basis for emission factors has changed over time. The objective here is to provide a data set as accurate as possible to the 2020 reference year.

The results are predominantly determined by assumptions for the following aspects: crop yields, as well as inputs and emissions from the cultivation of biomass, the efficiencies in the processing of the energy sources in particular, and the background data used.

The use of the BioEm tool initially provides a basis for a high level of agreement with the calculation of the RED II typical values. The reason is that this tool was developed specifically for the recalculation of these values and the consistent supplementation of non-GHG emissions. However, in order to establish a more up-to-date reference, the available data on actual values were also evaluated. For this purpose, the values published annually by the German competent authority were analysed. The results of the latest WTW study by the JEC (2020) were also reflected. From these analyses, trends were identified that allow a realistic assessment for settings for the reference year 2020.

Background data bases

As already mentioned, the calculation first refers to data bases for the calculation of the typical values of RED II. This relates in particular to data for the production of fertilisers. Deviations from this were made at various points. Of particular note here is electricity, where reference was made to the calculation described in the following chapter. The European energy mix for the year 2019 was generally used as a basis.

The data sources for transport emissions were not changed, although the present work provides explicit bases here. An adjustment of the BioEm model at this point would be extremely complex, however. It could not be done due to the time schedule of the project. Therefore, this is based on various data sources that were used by the authors of the RED II typical values. They also largely correspond to the data basis of the IEC (2020), but supplemented by the non-GHG emissions.

The EcoTransIT World GHG emission factors are also used in the ISO 14083, they are shown in Table 51 together with the lower heating values, densities and fossil CO₂ emissions.

Table 51 Emissions factors for biogenic fuels and gases

	density (d)	Lower heating value CO _{2e} -factor		or	CO ₂ -factor		
	, ,	MJ/kg	gCO₂e/MJ		gCO₂/MJ		
Fuel type description	kg/l	operational	operational	total	operational	total	
Biodiesel	0.892	37.0	4.1	38.3	4.0	24.0	
Ethanol	0.780	27.0	0.3	48.2	0	34.8	
HVO/ HEFA	0.770	44.0	0.1	28.6	0	19.1	
Bio CNG*	Χ	50.0	1.5	26.2	0	15.1	
Bio LNG*	Χ	50.0	1.5	30.4	0	19.3	
*only valid for SI trucks, v	alues for otl	her vehicles and engine t	ypes are differe	nt due to	methane slip		

Note: The non-zero value for fossil CO_2 in biodiesel is due to the presence of fossil methanol in the final biofuel product.

Table 52 summarises the non-GHG emission factors for the biofuels...

Table 52 Emission factors for energy production of biofuels (WTT)

Fuel	EC MJ/MJ	NOx mg/MJ	SO₂ mg/MJ	NMHC mg/MJ	PM mg/MJ
Biodiesel (50% rapeseed, 40% used cooking oil, 10% soybean)	1.308	71.95	32.93	4.96	4.75
Ethanol (40% maize, 35% sugar beet, 25% wheat)	1.849	95.56	25.02	7.13	5.08
Bio CNG (40% maize, 40% manure, 20% biowaste)	1.058	44.57	17.34	3.54	4.52
HVO/ HEFA* (50% rapeseed, 50% used cooking oil)	0.795	43.40	13.09	4.34	3.47
Bio LNG (40% maize, 40% manure, 20% biowaste)	1.168	51.13	22.58	4.07	5.80
Source: ifeu calculations					

^{*} HVO/ HEFA can also be used as a marine fuel or a sustainable aviation fuel

6.6.4 Emission factors for fossil and biogenic fuels in the US

The fuel emission factors for the US given in the ISO 14083 are used in ETW. Fuel properties, densities and GHG emissions are directly taken from the ISO 14083, however, all other emissions (energy demand, fossil CO2 emissions as well as air pollutant emissions) were added using the original source, which was the GREET database (GREET 2021).

The resulting fuel properties, GHG and fossil CO₂ emission values are shown in Table 53.

Table 53 Fuel properties and GHG emission factors for fossil fuels and gases (ISO 14083) + fossil CO_2 emissions

	density (d)	Lower	CO2e-fac	tor	CO2-factor	
		heating value MJ/kg	gCO₂e/MJ		gCO2/MJ	
Fuel type description	kg/l	operational	operational	total	operational	total
Gasoline	0.749	41.7	73.0	90.2	72.7	85.6
Ethanol (corn)	0.789	27.0	0.3	55.6	0	42.9
Diesel	0.847	42.6	75.0	90.5	74.9	87.3
Biodiesel (soybean)	0.881	37.7	4.1	20.6	4.0	18.0
HVO (tallow)	0.779	44.0	0.1	17.7	0	16.0
Liquefied Petroleum Gas (LPG)	0.508	46.0	64.8	78.5		
Compressed Natural Gas (CNG)	Х	47.1	56.8	73.7	56.2	64.8
Liquefied natural gas (LNG)	Х	48.6	57.0	76.7	56.5	85.9
Kerosene	0.802	43.2	73.2	84.6	73.2	81.6
Heavy Fuel Oil (HFO) (2.7% sulphur)	0.991	39.5	81.7	94.3	80.6	90.3
Very Low Sulphur Fuel Oil (VLSFO) (0.5% sulphur)	0.991	39.5	81.7	95.6	80.6	91.5
Ultra low sulphur fuel oil (ULSFO) (0.1% sulphur)	0.991	39.5	81.7	95.9	80.6	91.8
Marine diesel oil (MDO) (0.5% sulphur)	0.914	41.0	78.6	92.1	77.5	88.0
Marine Gas Oil (MGO) (1% sulphur)	0.837	42.8	75.1	87.8	74.1	83.8
*only valid for SI trucks, values for other vehic	cles and engine	types are differen	t due to methan	e slip.		

Sources: ISO 14083, GREET 2021

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

Fuel	EC	NOx	SO ₂	NMHC	PM
	MJ/MJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Gasoline	0.273	24.0	6.8	27.9	2.7
Ethanol (corn)	0.870	82.0	23.2	56.0	15.1
Diesel	0.183	16.9	4.5	7.0	1.2
Biodiesel (soybean)	0.480	19.0	9.0	19.0	1.0
HVO (tallow)	1.000	20.0	10.0	19.0	2.0
Liquefied Petroleum Gas (LPG)	0.141	18.6	17.2	11.1	0.9
Compressed Natural Gas (CNG)	0.154	38.6	12.2	10.4	0.7
Liquefied natural gas (LNG)	0.191	21.3	11.9	7.3	0.8
Kerosene	0.123	14.5	3.7	6.5	0.9
Heavy Fuel Oil (HFO) (2.7% sulphur)	0.136	18.5	6.0	5.7	1.4
Very Low Sulphur Fuel Oil (VLSFO) (0.5% sulphur)	0.156	18.8	6.2	5.9	1.4
Ultra low sulphur fuel oil (ULSFO) (0.1% sulphur)	0.161	18.8	6.2	5.9	1.4
Marine diesel oil (MDO) (0.5% sulphur)	0.149	18.7	6.1	5.8	1.4
Marine Gas Oil (MGO) (1% sulphur)	0.136	18.5	6.0	5.7	1.4
Source: GREET 2021					

Table 54 Emission factors for energy production of liquid and gaseous fuels (WTT)

Emission factors for electricity production 6.7

The emission factors of electricity production depend mainly on the mix of energy carriers and the efficiency of the production. The main problem of quantifying ecological impacts of electricity is that electrons cannot in actuality be traced to a particular power plant. According to ISO 14083, emission factors for electricity production shall be calculated using a location-based approach. In ETW we use the average electricity split per year and country. Since ETW calculates with the production mix of the countries, this approach is not yet completely ISO 14083-compliant, where a consumption mix is needed. However, we plan to update to consumption mixes with the next electricity data update.

Single companies often buy electricity on the marked (e.g. green electricity) with different energy mixes and therefore different emission factors. The ISO 14083 allows the use of such values on a company level in addition to the location-based mixes (dual-accounting). However, they cannot be used in the public version of ETW, because in many cases there is no information available about the company which runs the train on the selected destination or about the electricity used by a company. To be consistent, it is not possible to combine national and company specific values in the same emission balance, because double counting of emissions from the same energy source cannot be avoided.

Therefore, the marked based electricity mix can only be used in the business solution of ETW. In this case, the company is responsible for the quality of the emission values and fulfilling the requirements of EN ISO 14083. The public version consequently uses the national production mix for the emission calculation of all modes and processes.

The emission values for the national electricity production are calculated using the UMBERTO based "master network". This model has been maintained 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 Table 55) stems from EUROSTAT and the International Energy Agency (IEA) and the reference year is 2019. Data from the construction of the power plants and other infrastructure processes is included in the emission factor calculation.

Table 55 Energy split of electricity consumption in 2019

Region	Ref. year	Source	Fossils	Renewables	others (incl. Nuclear)
Africa	2019	IEA	77.4%	21.0%	1.6%
South Africa	2019	IEA	89.3%	5.3%	5.4%
Asia (excl. China)	2019	IEA	76.7%	20.4%	2.9%
China (incl. Hong Kong)	2019	IEA	67.4%	27.9%	4.8%
Hong Kong	2019	IEA	99.7%	0.1%	0.2%
India	2019	IEA	76.3%	20.7%	3.0%
Japan	2019	IEA	73.2%	18.6%	8.2%
South Korea	2019	IEA	69.5%	4.8%	25.7%
Australia	2019	IEA	79.7%	20.3%	0.0%
Non-OECD Americas	2019	IEA	28.9%	68.8%	2.3%
Brazil	2019	IEA	14.0%	83.1%	2.8%
Chile	2019	IEA	52.3%	47.7%	0.0%
Mexico	2019	IEA	79.2%	17.3%	3.4%
Bosnia and Herzegovina	2019	IEA	61.8%	38.2%	0.0%
Israel	2019	IEA	95.1%	4.9%	0.0%
Switzerland	2019	IEA	0.9%	59.4%	39.7%
Non-OECD Eurasia	2019	IEA	61.9%	20.0%	18.1%
United States	2019	IEA	62.2%	18.1%	19.7%
Canada	2019	IEA	17.3%	67.4%	15.3%
Middle East	2019	IEA	96.9%	2.5%	0.6%
Islamic Republic of Iran	2019	IEA	92.2%	5.5%	2.2%
Former Soviet Union	2019	IEA	63.2%	18.4%	18.4%
Russian Federation	2019	IEA	62.7%	18.5%	18.9%

World	2019	IEA		62.3%		26.9%	10.7%	
			Coal	Oil	Gas	Renewables	Nuclear	other
EU 28	2019	EUROSTAT	14.1%	1.4%	23.2%	34.4%	25.4%	1.5%
Austria	2019	EUROSTAT	2.0%	0.7%	19.5%	76.2%	0.0%	1.6%
Belgium	2019	EUROSTAT	0.1%	0.0%	30.6%	20.4%	46.6%	2.3%
Bulgaria	2019	EUROSTAT	38.4%	0.6%	5.3%	17.7%	37.9%	0.1%
Croatia	2019	EUROSTAT	12.3%	0.2%	20.8%	66.7%	0.0%	0.0%
Cyprus	2019	EUROSTAT	0.0%	89.5%	0.0%	10.5%	0.0%	0.0%
Czech Republic	2019	EUROSTAT	42.8%	0.1%	9.6%	11.8%	35.6%	0.2%
Denmark	2019	EUROSTAT	10.6%	0.3%	7.6%	75.8%	0.0%	5.6%
Estonia	2019	EUROSTAT	75.7%	0.7%	6.5%	16.0%	0.0%	1.1%
Finland	2019	EUROSTAT	10.4%	0.4%	6.7%	46.2%	34.8%	1.6%
France	2019	EUROSTAT	0.6%	1.0%	7.5%	20.3%	69.9%	0.8%
Germany	2019	EUROSTAT	27.6%	0.6%	17.2%	40.2%	12.4%	2.0%
Greece	2019	EUROSTAT	25.6%	10.6%	26.5%	36.7%	0.0%	0.6%
Hungary	2019	EUROSTAT	11.5%	0.1%	26.1%	13.4%	47.7%	1.1%
Ireland	2019	EUROSTAT	7.5%	0.9%	51.6%	38.1%	0.0%	1.9%
Italy	2019	EUROSTAT	6.2%	2.7%	50.3%	39.3%	0.0%	1.6%
Latvia	2019	EUROSTAT	0.0%	0.0%	50.3%	49.7%	0.0%	0.0%
Lithuania	2019	EUROSTAT	0.0%	1.1%	17.6%	77.3%	0.0%	4.0%
Luxembourg	2019	EUROSTAT	0.0%	0.0%	18.1%	70.7%	0.0%	11.2%
Malta	2019	EUROSTAT	0.0%	1.4%	87.8%	10.8%	0.0%	0.0%
Montenegro	2019	EUROSTAT	39.1%	0.0%	0.0%	60.9%	0.0%	0.0%
Netherlands	2019	EUROSTAT	14.1%	0.1%	62.0%	17.6%	3.2%	3.1%
Norway	2019	EUROSTAT	0.0%	0.0%	1.8%	97.9%	0.0%	0.2%
Poland	2019	EUROSTAT	71.6%	1.1%	10.9%	16.0%	0.0%	0.4%
Portugal	2019	EUROSTAT	10.1%	2.1%	33.5%	53.1%	0.0%	1.1%
Romania	2019	EUROSTAT	22.1%	0.3%	16.1%	42.8%	18.8%	0.0%
Serbia	2019	EUROSTAT	67.9%	0.1%	2.1%	29.9%	0.0%	0.0%
Slovakia	2019	EUROSTAT	8.0%	1.5%	12.5%	23.8%	54.0%	0.2%
Slovenia	2019	EUROSTAT	27.3%	0.1%	3.4%	32.7%	36.4%	0.1%
Spain	2019	EUROSTAT	4.5%	4.5%	31.7%	37.4%	21.2%	0.6%
Sweden	2019	EUROSTAT	0.2%	0.1%	0.6%	58.7%	38.4%	1.9%
Turkey	2019	EUROSTAT	35.4%	0.1%	31.5%	33.0%	0.0%	0.0%
United Kingdom	2019	EUROSTAT	2.0%	0.2%	41.3%	36.8%	17.2%	2.5%

Due to confidentiality reasons, IEA data is given in a higher granularity.

Table 55 shows the emission values at pantograph for the different countries/ regions.

Table 56 Energy and emission factors of the electricity supply for railway transport (WTT at pantograph, country-based production mix) in 2019 (including infrastructure)

Pagion	Energy factor	CO _{2e}	CO ₂ ,	NO _x	SO ₂	NMHC	PM10
Region	(MJ/ MJ)	(g/ MJ)	(g/ MJ)	(g/MJ)	(g/ MJ)	(g/ MJ)	(g/ MJ)
Africa	3.15	247	236	0.542	0.692	0.039	0.059
Asia (excluding China)	2.88	270	261	0.662	0.743	0.039	0.056
Austria	1.35	52	47	0.071	0.085	0.014	0.015
Australia	2.95	268	258	0.439	0.516	0.041	0.049
Bosnia	2.79	273	268	0.219	1.116	0.009	0.071
Belgium	2.91	57	53	0.072	0.081	0.017	0.017
Bulgaria	3.50	176	171	0.180	0.696	0.014	0.052
Brazil	1.47	43	39	0.092	0.113	0.015	0.017
Canada	2.04	54	51	0.071	0.121	0.015	0.017
Switzerland	2.39	7	6	0.025	0.061	0.006	0.015
Chile	2.10	164	154	0.484	0.243	0.037	0.029
China (including Hong Kong)	2.33	230	224	0.764	0.675	0.026	0.053
Cyprus	3.43	255	246	0.294	1.233	0.125	0.067
Czech Republic	3.46	196	187	0.204	0.561	0.015	0.044
Germany	2.27	137	128	0.140	0.154	0.018	0.020
Denmark	1.26	55	48	0.170	0.100	0.013	0.020
Estonia	2.39	253	240	0.317	1.008	0.015	0.065
Greece	2.51	188	182	0.176	0.487	0.046	0.037
Spain	2.38	80	76	0.122	0.169	0.025	0.023
EU28	2.57	101	94	0.163	0.231	0.022	0.028
Finland	2.34	54	49	0.150	0.105	0.012	0.018
France	3.75	25	23	0.048	0.080	0.011	0.018
FSU 15	3.28	193	178	0.304	0.313	0.053	0.043
Hong Kong	2.81	303	292	0.887	0.779	0.052	0.059
Croatia	1.80	86	77	0.197	0.168	0.018	0.031
Hungary	3.40	102	95	0.137	0.232	0.024	0.026
Ireland	1.80	104	101	0.123	0.099	0.017	0.017
Israel	2.78	226	215	0.449	0.398	0.027	0.055
India	2.82	295	287	0.857	1.137	0.031	0.080
Iran	3.00	202	194	0.196	0.212	0.035	0.025
Italy	2.13	122	111	0.169	0.158	0.041	0.022
Japan	2.47	185	173	0.361	0.264	0.046	0.031
South Korea	3.11	193	182	0.492	0.487	0.037	0.056
Lithuania	1.54	53	45	0.132	0.100	0.018	0.021
Luxembourg	1.30	52	42	0.153	0.087	0.018	0.020
Latvia	1.61	87	73	0.146	0.114	0.036	0.019
Montenegro	2.15	171	168	0.141	0.712	0.007	0.048

Middle East	3.42	245	229	0.255	0.486	0.109	0.033
Malta	1.99	152	144	0.139	0.144	0.046	0.018
Mexico	2.73	173	162	0.243	0.423	0.065	0.035
Netherlands	1.85	132	126	0.140	0.119	0.029	0.019
Norway	1.16	6	6	0.016	0.053	0.004	0.012
Non-OECD America	1.85	78	72	0.126	0.202	0.032	0.021
Non-OECD Europe and Eurasia	3.41	202	185	0.282	0.485	0.047	0.044
Poland	2.80	281	257	0.543	0.750	0.021	0.067
Portugal	1.74	95	90	0.182	0.192	0.030	0.023
Romania	2.77	142	137	0.134	0.491	0.021	0.038
Serbia	2.82	288	282	0.228	1.140	0.010	0.072
Russian Federation	3.34	193	179	0.273	0.324	0.054	0.040
Sweden	2.38	9	8	0.055	0.064	0.006	0.015
Slovenia	2.96	103	100	0.100	0.328	0.008	0.030
Slovakia	3.41	68	61	0.119	0.183	0.017	0.025
Turkey	2.36	171	163	0.175	0.198	0.024	0.022
United Kingdom	2.13	80	72	0.124	0.096	0.026	0.018
United States	2.82	156	148	0.210	0.252	0.033	0.026
World	2.74	194	183	0.426	0.433	0.032	0.048
South Africa	4.00	381	375	1.348	1.017	0.052	0.162

6.8 Biofuel shares

Environmentally sustainable biofuels are an option to reduce GHG emissions but at a high percentage blend they may cause troubles to classical vehicles e.g. engine shut down, issues of compatibility with metals, elastomers (fuel lines and gaskets) or winter grade property of the fuel). In order to ensure a safe operation for all vehicles without harmful consequences, the European Standard EN 590 permits biodiesel blends with up to 7% of FAME¹² and 30% for hydro treated vegetable oil (HVO¹³). Lower blends such as B5 are also proposed. Higher blends such as B20, B30 or pure biodiesel may be used in certain vehicles (designated by manufacturers) or in dedicated vehicles. Nevertheless, these options have not penetrated the market very strongly. According to Eurostat in the EU 28

¹² Fatty Acid Methyl Ester

¹³ Hydrotreated Vegetable Oils

biodiesel incorporation in the diesel pool has fluctuated over the last 5 years, and reached 5.9% (lower heating value) in 2018.

EcoTransIT includes values for the average share of Biodiesel (incl. HVO) in diesel (biodiesel share in %= biodiesel/(diesel+biodiesel) based on energy content see 2009/28/EC RED directive) in the different countries.

Data for the European countries was taken from EUROSTAT and is valid for the year 2018. Other data source may account for slightly different biofuel shares; however, a validation of the Eurostat data from 2015 and the UN data from the same year showed a good overall reliability of the data. The UN data from 2017 was used for countries not given in Eurostat. It must be noted that the UN database is in given in metric tons, requiring us to convert in TJ using default lower calorific values (EN16258) which may lead to slight discrepancies as the lower calorific value of biodiesel depends on feedstock, which are not detailed in the UN database.

For the countries in Table 57 country-specific biofuel shares are used. The numbers reflect the share of biofuels 2018 in energy content and can vary from official data on the share of renewable energy sources (RES). 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 2017, which leads to an inconsistency between the two data sources. EcoTransIT users have however requested to always use the newest data possible; therefore, data from 2018 from Eurostat and data from 2017 from the UN database are combined.

In previous versions, biofuel shares were not distinguished between road, rail or water transport. However, newer data from the Eurostat database showed that most countries use biodiesel solely for their road transport segment.

EUROSTAT has no data available for biodiesel in water or rail transport, but only gives an amount of biodiesel used for transports other than road transports. Through desktop research it was found that only Portugal uses biodiesel in shipping. In Austria, Czech Republic, Germany, Greece, Latvia, Lithuania and the Netherlands biodiesel is used for rail transport. Since no reliable amounts for biodiesel usage in rail/ water were found, whenever a country uses biodiesel for anything other than road transport, the same number as for the road biodiesel share is given.

Table 57: Share of biodiesel in total diesel for road transport in the different countries (MJ/MJ)

Country	Reference year	Source	Biodiesel share
China (incl. Hong Kong)	2017	UN database	6.7%
Australia	2017	UN database	0.03%
Brazil	2017	UN database	7.2%
Austria	2018	EUROSTAT	5.6%
Belgium	2018	EUROSTAT	5.4%
Bosnia and Herzegovina	2018	EUROSTAT	0.0%
Bulgaria	2018	EUROSTAT	6.3%
Croatia	2018	EUROSTAT	1.8%
Cyprus	2018	EUROSTAT	2.9%
Czech Republic	2018	EUROSTAT	5.3%
Denmark	2018	EUROSTAT	6.4%
Estonia	2018	EUROSTAT	2.4%
Finland	2018	EUROSTAT	10.8%
France	2018	EUROSTAT	8.3%
Germany	2018	EUROSTAT	5.4%
Greece	2018	EUROSTAT	6.7%
Hungary	2018	EUROSTAT	4.6%
Ireland	2018	EUROSTAT	4.1%
Italy	2018	EUROSTAT	5.4%
Latvia	2018	EUROSTAT	3.5%
Lithuania	2018	EUROSTAT	4.2%
Luxembourg	2018	EUROSTAT	6.5%
Malta	2018	EUROSTAT	7.0%
Netherlands	2018	EUROSTAT	5.6%
Norway	2018	EUROSTAT	12.9%
Poland	2018	EUROSTAT	5.0%
Portugal	2018	EUROSTAT	5.7%
Romania	2018	EUROSTAT	4.5%
Serbia	2018	EUROSTAT	0.0%
Slovakia	2018	EUROSTAT	6.8%
Slovenia	2018	EUROSTAT	4.4%
Spain	2018	EUROSTAT	6.4%
Sweden	2018	EUROSTAT	22.5%
Switzerland	2017	UN database	3.7%
Turkey	2018	EUROSTAT	0.5%
United Kingdom	2018	EUROSTAT	3.4%
United States	2017	UN database	3.4%
Canada	2017	UN database	3.6%
EU 28	2018	EUROSTAT	6.0%
Japan	2017	UN database	0.1%
World	2017	Default value	0.01%

For some countries, no data was available in Eurostat or from the UN. For each of them a search has been carried out to ensure that they do not consume a relevant amount of biodiesel. If this was the case, there biodiesel share was set to the default value of 0.01%. This concerns the following countries: South Africa, India, Iran, Chile, Israel, Mexico, Russian Federation and South Korea as well as the regions Africa, Asia, Non-OECD Americas, Non-OECD Eurasia, Middle East and the Former Soviet Union.

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

Only a very limited number of European countries use bio methane for transport purposes and all bio methane is being used solely in road transport. Shares of bio methane for the year 2018 were taken from EUROSTAT and are shown in Table 58.

Country	Reference year	Source	Biodiesel share
EU 28	2018	EUROSTAT	8.6%
Germany	2018	EUROSTAT	21.0%
Austria	2018	EUROSTAT	2.2%
Finland	2018	EUROSTAT	12.5%
Sweden	2018	EUROSTAT	91.2%
Iceland	2018	EUROSTAT	100%
Norway	2018	EUROSTAT	38.3%

Table 58: Share of bio methane in road transport

Cooled transports 6.9

Most refrigerated transports today call for an active cooling of the freight during transportation. To achieve this, often an additional energy demand result. Since it is also within the scope of EN 16258, cooled transports are now being included in ETW. As a first step, cooling transports for container transport on trucks and rail will be integrated. Only for trucks are bulk refrigerated transports also possible in ETW.

In addition to the energy demand for cooling, the used refrigerant and its leakage rates have a big impact on GHG emissions. Most refrigerants have a very high global warming potential that can be more than 2.000 times higher than that of CO₂ and annual leakages can be around 10% of the initial refrigerant charge [Tassou, et al., 2009]. However, refrigerant leakages are not in the scope of EN 16258 and will therefore not be included here. Further research on refrigerant leakages and the type of refrigerants used in the different countries may be done later to achieve a more complete picture of the entire environmental impacts of cooling transports.

Due to the high complexity of cooling transports, only a very rough estimation of the possible environmental impacts will be possible in ETW. 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 the different transport modes. Only refrigerated freight transports needing an active cooling will be considered here.

Most of these transports 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 is usually taken into account with the storage processes and not with the actual transportation chain [Kranke, et al., 2011].

There are also smaller refrigerated trucks in operation with an insulated box compartment and an integrated cooling unit. Their cooling machine is most often run by the main truck engine, but may also be supplied by a separate diesel engine.

The most common forms of cooled transports are shown in Table 59 and are included into ETW.

Table 59 Overview on refrigerated transport modes in ETW
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Articulated Truck (60 t)	Rigid Truck (≤40t)	Train	Ship (not yet included in ETW)	Aircraft (not included in ETW)
Trailer with reefer Power supply with clip-on diesel genset	Truck with integrated cooling unit (box) Power supply from main engine	Waggon with reefer Power supply with clip-on diesel genset	Container ship with reefers Power supply from onboard electricity (supplied by auxiliary engine)	dry-ice cooled containers with a battery- electric fan Power supply from ground electricity

In ETW the same reefer container, a 40-foot high cube container with a capacity of 2 TEU, will be used for ships, trains and articulated trucks (gross weight of more than 40 t). Its specifications are shown in Table 60.

Specifications of the reefer (40' high-cube container) Table 60:

External dimensions	H: 2.896 m / L: 12.192 / W: 2.438 m
Weight	4100 kg (4480 kg with refrigeration unit)
Maximum gross weight	34000 kg
Maximum payload	29510 kg

Source: [Weidema, et al., 2013]

To calculate the energy demand and emissions from cooling the average power demand of the reefer is needed. 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.

In EcoTransIT we use an average power consumption of 2.7 kW/TEU [Fitzgerald 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 traveled but rather on the time needed for the transport. Using the average speed (including breaks) the cooling demand per hour can be allocated to the distance travelled. Currently, the average speeds from [Weidema, et al., 2013] are used, which are 45 km/h for trucks and 40 km/h for trains (including breaks).

Trains and larger trucks can transport the same reefers. For both transport modes, 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 TREMOD MM. 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 in 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.

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

Energy demand and emissions from diesel generator sets with 18 kW per kWh [ifeu, 2015] Table 61:

For rigid trucks (≤40t) we assume that the trucks cooling unit is powered by the main diesel engine. It therefore results in an additional diesel demand that according to [Tassou, et al., 2009] should lie between 15-25% of the diesel demand for driving. To give a very rough estimation of possible additional fuel demand 20% fuel consumption will be added. The energy consumption also depends on how often the cooling compartment is opened which is especially expected for distribution trucks. Due to low data availability no distinction between multi-drop or single- drop will be done.

Refrigerated transports in airplanes are also possible. Here however a special airfreightcooling container has to be used. Most air transports do not use an active cooling unit, since safety regulations prohibit the use of diesel generators on board and the plane cannot supply the additional electricity demand. Therefore, airplanes use dry-ice cooled containers with a battery- electric fan. This battery is charged on the ground and therefore not included in the transport emissions in ETW.

Onboard sea ships or barges the reefer can be directly connected to the ship's electricity circuit. Electricity on ships is generated by using an auxiliary engine, which is already contained in ETW. Therefore, refrigerated transports on sea ships and barges will be calculated by adding an additional demand on the ship's auxiliary engines. The ship methodology for cooled transports is however not completed yet, and will be integrated in one of the next EcoTransIT versions.

^{*} Diesel demand taken from ThermoKing

7 Appendix

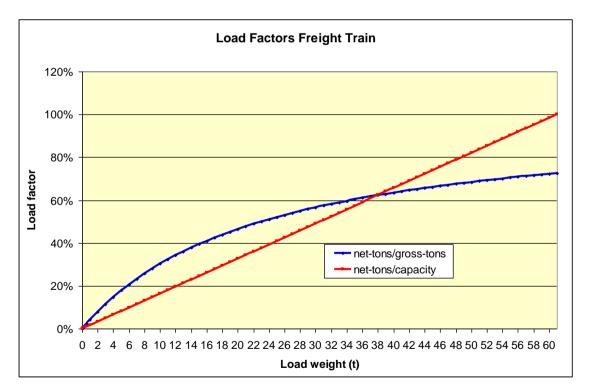
7.1 Additional information to load factors

In this chapter some explanations about the load factor of trains and containers are given in addition to chapter 4.2.2.

7.1.1 Train

The load factor for trains is originally defined as the relation of net tonnes / gross tonne. For a better comparison with road and ship 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 ETW (see chapter 4.2.1: empty weight: 23 tonnes, payload capacity: 61 tonnes).

Figure 25 Load factors for freight trains



7.1.2 Container

Many cargoes shipped in containers are light weight consumer goods¹⁴. The emissions per TEU-km are allocated 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 ship 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 62).

Average cargo:

In accordance with Clean Cargo the net weight of average goods is be defined by 10.0 tonnes per TEU /CCWG 2014/. Cargo is transported in 20' and 40' containers in the ratio of approximately 2 to 5, i.e. 2 TEU to 10 TEU¹⁵. Thus, for each lift¹⁶ an average of 1.7 TEUs is loaded. The average empty weight of a TEU is 1.95 tonnes¹⁷.

Volume cargo:

For determining 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 % 18 to its weight carrying capacity is assumed to

¹⁴ 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.

¹⁵ A ratio of 1.7 was determined by comparing lifts and TEUs handled from port statistics.

¹⁶ Lift is an expression from container terminals and describes the number of containers loaded on-board of vessels.

¹⁷ Calculated from a mix of 20' and 40' containers.

¹⁸ 50 % of the container weight capacity utilised to a maximum of 90 %.

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. In order 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 average¹⁹ and an average empty container weight of 2.0 tonnes. A theoretical model 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 62: Container net-cargo weights for EcoTransIT 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 is capable of carrying 2 TEUs. If containers are further transported by road, it is recommended not to exceed 18 tonnes per TEU for heavy weight cargo.

Assuming a maximum utilisation by weight of 90 %. 19

For intermodal transport - the continuing of transport on land-based vehicles - the weight of the container is added to the net-weight of the cargo. Table 9 on page 16 provides the values used in ETW.

Detailed data of aircrafts included in EcoTransIT 7.2

Table 63 Design range, payload and seats of selected types of aircrafts

Туре	Aircraft Code	Type of Aircraft	Design Range [km]	Max. Payload [t]	Typical Seats [number]
Freighter	ABY	Airbus 300-600F	4,850	48.1	
Freighter	31Y	Airbus 310-300F	5,560	39.1	
Freighter	33X	Airbus 330-200F	7,400	65.0	
Freighter	ATY	ATR 72-200F	960	7.8	
Freighter	14F	BAe 146-300QT	1,930	12.5	
Freighter	M1F	Boeing (McDonnell Douglas) MD-11F	6,700	89.6	
Freighter	72F	Boeing 727F	2,570	29.5	
Freighter	73Y	Boeing 737-300SF	3,030	19.7	
Freighter	74X	Boeing 747-200F	6,640	111.0	
Freighter	74Y	Boeing 747-400F	8,250	113.0	
Freighter	74N	Boeing 747-8F	8,130	133.9	
Freighter	75F	Boeing 757-200PF	5,830	32.8	
Freighter	76X	Boeing 767-200F	5,790	45.0	
Freighter	77X	Boeing 777-200F	8,410	102.9	
Belly	319	Airbus 319	3,300	1.7	124
Belly	320	Airbus 320	5,700	2.4	150
Belly	321	Airbus 321	5,500	2.8	185
Belly	332	Airbus 330-200	12,500	17.5	253
Belly	333	Airbus 330-300	10,500	21.0	295
Belly	346	Airbus 340-600	13,900	22.0	380
Belly	388	Airbus 380-800	15,000	20.0	525
Belly	M90	Boeing (McDonnell Douglas) MD-90	3,860	3.0	153
Belly	734	Boeing 737-400	4,010	3.5	147
Belly	738	Boeing 737-800	3,590	4.0	162
Belly	744	Boeing 747-400	13,450	16.8	416
Belly	74H	Boeing 747-8i	14,820	17.4	467
Belly	752	Boeing 757-200	7,220	3.8	200
Belly	763	Boeing 767-300	10,310	13.7	218
Belly	772	Boeing 777-200/200ER	9,700	19.0	305
Belly	77W	Boeing 777-300ER	14,490	23.0	365
Belly	788	Boeing 787-8	14,200	15.8	242
Belly	E90	Embraer 190	3,330	1.4	98

8 References

8.1 General

- Borken 1999 Borken, J., Patyk, A., Reinhardt, Guido A., ifeu: Basisdaten für ökologische Bilanzierungen – Einsatz von Nutzfahrzeugen in Transport, Landwirtschaft und Bergbau; Verlag Vieweg, ISBN 3-528-03118-2; Braunschweig/Wiesbaden 1999
- Carstens 2000 Stefan Carstens, Hans Ulrich Diener: Güterwagen Band 2, Gedeckte Wagen -Sonderbauart. MIBA-Verlag, Nürnberg 2000; citation in: http://en.wikipedia.org/wiki/Covered goods wagon
- DB Schenker 2012 Internal survey: key values of freight transport from railway transport statistics, 2012
- EN DIN 2012 EN DIN 16258:2012 Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (passenger and freight), 21.11.2012 **ePure 2016** Overview of the biofuel policies and markets across the EU-28. No.June.
- Fraunhofer IML 2019 Dobers, K., Rüdiger, D. & Jarmer, J.-P.: Guide for Greenhouse Gas Emissions Accounting at Logistics Sites. (2019). http://publica.fraunhofer.de/documents/N-532019.html
- GDV 2010 Containerhandbuch / Container Handbook. Gesamtverband der Deutschen Versicherungswirtschaft e.V. http://www.containerhandbuch.de/
- **IEA 2015** IEA advanced Motor fuels Annual report Sweden.
- ifeu / INFRAS / IVE 2014 EcoTransIT World Ecological Transport Information Tool for Worldwide Transports. Methodology and Data Update. Commissioned by EcoTransIT World Initiative (EWI). Berne - Hannover - Heidelberg, 4th December 2014.
- ifeu 1999 Knörr, W. et al.: Mobilitäts-Bilanz Energieverbrauch und Emissionen im Personen- und Güterverkehr mit verschiedenen Verkehrsmitteln; Erstellung verschiedener Materialien und Tools im Auftrag der DB AG; 1998 - 2000; Veröffentlichung der "Mobilitäts-Bilanz" und der Software "Reisen und Umwelt" im Okt. 1999
- KBA 2013 KBA and BAG: Verkehr deutscher Lastkraftfahrzeuge; VD5, Dezember 2013
- KBA 2002 Güterkraftverkehr deutscher Lastkraftfahrzeuge; Reihe 8, Heft 12, Dezember 2001
- Kessel und Partner 1998 Kienzler, H.-P.: Kapazitätsauslastung und Leerfahrten im Gütertransport; VDA Materialien zur Automobilindustrie, Heft 16; Frankfurt am Main 1998
- **Sbb 2017** Auto diesel sales exceeded 3 billion litres in 2016. pp. 1–5.
- **SNCF Geodis 2012** Internal survey: key values of freight transport from railway transport statistics, 2012
- Van de Reyd and Wouters Van de Reyd, J.K.R., Wouters, M.V.L.J.: Air Cargo Density Research. **Delft 2005**
- ifeu/ infras/ Öko Institut 2020 Allekotte, M.; Bergk, F.; Biemann, K.; Deregowski, C.; Knörr, W.; Althaus, H.J.; Sutter, D.; Bergmann, T.: Ökologische Bewertung von Verkehrsarten -Abschlussbericht. Im Auftrag des Umweltbundesamtes 2020
- Ricardo, ifeu, e4tech 2020: Ricardo, ifeu, e4tech: Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA. Im Auftrag European Commission, DG Climate Action.

8.2 Road transport

last visit in April 2016

from, http://www.epa.gov/otag/models/moves/

- Dieselnet 2014 DieselNet Online information service on clean diesel engines and diesel emissions: Summary of worldwide emission standards, http://www.dieselnet.com, last visit October 10th, 2014
- CE DELFT 2013 Zero emissions trucks: an overview of state-of-the-art technologies and their potential.
- dieselnet.com Online information service on clean diesel engines and diesel emissions: Summary of worldwide emission standards. http://dieselnet.com/standards/, last visit in April 2016
- DLR / LBST / IFEU / DBFZ 2015 Identifizierung von Hemmnissen der Nutzung von LNG und CNG im schweren Lkw-Verkehr sowie Möglichkeiten zu deren Überwindung. Berlin, München, Heidelberg, Leipzig.
- energy.gov.il Ministry of national infrastructure, energy and water resources (Israel): Fuel and the Environment. http://energy.gov.il/English/Subjects/Subject/Pages/GxmsMniFuelAndTheEnvironment.aspx,
- EPA 2014 Motor Vehicle Emission Simulator (MOVES), Version 2014a, by EPA Office for Transportation and Air Quality, retrieved from, http://www.epa.gov/otag/models/moves/EPA 2009 Motor Vehicle Emission Simulator (MOVES), Version 2009/12/21, by EPA Office for Transportation and Air Quality, retrieved
- INFRAS 20122 Notter, B. et al, INFRAS, et al: Handbook Emission Factors for Road Transport, Ver. 4.2, Bern 2022
- integer.com Industry Insight International Diesel Emissions Regulation https://www.integerresearch.com/industry-insight/emissions-legislation/, last visit in April 2016
- NGV Global Current Natural Gas Vehicle Statistics Natural Gas Vehicle Knowledge Base. http://www.iangv.org/current-ngv-stats/ (23.05.2017).
- NGVA European map of CNG & LNG filling stations get directions. http://www.ngva.eu/get-directions (05.07.2017).
- 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-towheel emissions
- transportpolicy.net Fuels: Diesel and Gasoline in the US, Australia and Canada, http://transportpolicy.net/index.php?title=Australia:_Fuels:_Diesel_and_Gasoline http://transportpolicy.net/index.php?title=Canada:_Fuels:_Diesel_and_Gasoline http://transportpolicy.net/index.php?title=US:_Fuels:_Diesel_and_Gasoline last visit in April 2016
- trend news agency 2013 Iranian dangerous fuels with 180 to 8000 ppm sulphur, trend news agency 2013, http://en.trend.az/iran/2106825.html, last visit in April 2016
- UNEP 2007 Opening the door to cleaner vehicles in developing and transition countries: the role of low sulphur fuels. UNEP (PCFV) 2007 http://www.unep.org/transport/pcfv/pdf/sulphurreport.pdf last visit in April 2016
- USCB 2004 U.S. Census Bureau 2002 Economic Census: Vehicle Inventory and Use Survey (VIUS); EC02TV-US, Washington DC, 2004
- USDOE 2009 U.S. Departement of Energy: Transportation Energy Data Book, Edition 28, 2009
- USDOT 2007 U.S. Departement of Transport Federal Highway Administration: Development of Truck Payload Equivalent Factor (TPEF), Columbus, 2007

8.3 Rail transport

- DB 2008 Deutsche Bahn AG, Bahn-Umwelt-Zentrum: Energy and emission figures 2008
- DB Schenker 2012 Internal survey: key values of freight transport from railway transport statistics. 2012
- EPS 2005 Railway Association of Canada and Environment Canada: Locomotive Emissions Monitoring Program 2003; Environmental protection series: EPS 2/TS/17; 2005
- IFEU 2003: Erarbeitung von Basisemissionsdaten des dieselbetriebenen Schienenverkehrs unter Einbeziehung möglicher Schadstoffminderungstechnologien – Weiterführung und Auswertung des UBA-FuE-Vorhabens 299 43 111. Im Auftrag der Deutschen Bahn AG, Heidelberg.
- ifeu 2008 Sectoral analysis of motorised traffic in China; commissionned by Kreditanstalt für Wiederaufbau (KfW); Heidelberg, 2008
- Railway companies 2002 Different internal statistics DB, DSB, SBB, SJ, SNCB, SNCF und TI about railway operation data, energy consumption, train configuration etc., 2002
- SBB 2006 Enotrac AG: Simulationsrechnungen für Re 420 und Re 620; unpublished: March 2006
- **SNCF Geodis 2012** Internal survey: key values of freight transport from railway transport statistics, 2012
- TRT 2008 TRT Trasporti e Territorio Srl: EX-TREMÌS (Exploring non road Transport EMISsions in Europe): Development of a Reference System on Emission Factors for Rail, Maritime and Air Transport; Final Report; commissionned by JRC-IPTS; Milan, 19 June 2008
- UIC 2005 UIC/CER: Rail Diesel Study (EU funded) WP1: Status and future development of the diesel fleet; Final Report; 21.07.2005

UIC 2007 UIC Statistic

UIC 2009 UIC Energy and CO2 Database; 2009

USDOT 2008 Energy Intensity of Class I Railroad a Freight Service

8.4 Inland ship and Marine transport

- Allekotte 2021: Aktualisierung des "Daten- und Rechenmodells: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland (TREMOD)" und der Datenbank "Mobile Maschinen und Geräte (TREMOD-MM)" 2021.
- Amos, P., Dashan, J., Tao, N., Junyan, S., 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. World Bank and Waterborne Transport Institute of MOT. http://siteresources.worldbank.org/EXTPRAL/Resources/china.pdf [accessed on 02.02.2016]
- BMVBS 2011 Kompendium Nutzen-Kosten-Analyse (NKA) für Investitionen an Binnenschifffahrtsstraßen, Ausgabe 2011. Bundesministerium für Verkehr, Bau und Stadtentwicklung, Unterabteilung Wasserstraßen, Berlin.
- BVB 2009 The power of inland navigation. The future of freight transport and inland shipping in Europe 2010 – 2011. Published by the Dutch Inland Shipping Information Agency (BVB).
- CEMT 1992 Resolution No. 92/2 on New Classification of Inland Waterways. Conférence Européenne des Ministres des Transports (CEMT). Athens. http://www.internationaltransportforum.org/IntOrg/acquis/wat19922e.pdf [accessed on 02.02.2016]
- Dieselnet 2015 Emission Standards International: IMO Marine Engine Regulations. https://www.dieselnet.com/standards/inter/imo.php [accessed on 02.02.2016]
- Marine Compression-Ignition (CI) Engines, model years 2000-2022. https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehiclesengines-and-equipment (30.09.2021).

- Fathom 2015 Marine Scrubbers: The Guide 2015. The Comprehensive Resource for Marine SOx Scrubbers. Fathom Maritime Intelligence, Windsor.
- FOEN 2015: Non-road energy consumption and pollutant emissions. Study for the period 1980 to 2050. Environmental studies no. 1519. Federal Office for the Environment (FOEN), Ittigen. http://www.bafu.admin.ch/publikationen/publikation/01828/index.html [Accessed 16. December 20151.
- Heidt et al. 2016: Weiterentwicklung des TREMOD-Binnenschiffmoduls. Teilbericht des Projekts "Ermittlung von Emissionsfaktoren von Kraftfahrzeugen unter Berücksichtigung zukünftiger Antriebskonzepte und der Vorkette von Kraftstoffen" FKZ 3713 47 100
- Holmegard and Hagemeister 2011 Environmental Performance Evaluation of Ro-Ro Passenger Ferry Transportation. Proceedings from the Annual Transport Conference at Aalborg University, ISSN 1603-9696, www.trafikdage.dk/artikelarkiv [accessed on 26.11.2017].
- ICCT 2021: Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit. International Council on Clean Transportation (ICCT). https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf [Accessed 3. June 2022].
- ifeu and INFRAS 2013 Aktualisierung der Emissionsberechnung für die Binnenschifffahrt und Übertragung der Daten in TREMOD. Im Auftrag des Umweltbundesamtes, FKZ 3711 45 105. Institut für Energie- und Umweltforschung (ifeu) und INFRAS, Heidelberg und Bern. https://www.ifeu.org/verkehrundumwelt/pdf/ifeu%202014 Bericht%20Binnenschifffahrt%20TR EMOD.pdf [accessed on 02.02.2016]
- IMO 2015 Third IMO Greenhouse Gas Study 2014. Executive Summary and Final Report. International Maritime Organization (IMO), London. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Thir d%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.p df [accessed on 01.02.2016]
- IMO 2019: IMO 2020: Taking bold action to clean up shipping emissions by reducing the sulphur content in ships' fuel oil. International Maritime Organization (IMO). https://www.cdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/Sulphur%2020 20%20infographic%202%20page.pdf [Accessed 3. June 2022].
- IMO 2020: Fourth IMO Greenhouse Gas Study. Final Report. International Maritime Organization (IMO), London. https://www.cdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO %20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf [Accessed 3.
- IMO 2009 Second IMO Greenhouse Gas Study 2009. International Maritime Organisation (IMO) London, UK.
- Jalkanen, J.-P., Johansson, L., Kukkonen, J., Brink, A., Kalli, J., Stipa, T. 2012 Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon dioxide. Atmospheric Chemistry and Physics 12, 2641-2659, 2012. http://www.atmos-chemphys.org/12/2641/2012/acp-12-2641-2012.pdf [accessed on 02.02.20126]
- MAN 2006 Basic Principles of Ship Propulsion. Technical Paper by MAN DW.
- Panteia 2013 Contribution to impact assessment of measures for reducing emissions of inland navigation. European Commission (EC). http://ec.europa.eu/transport/modes/inland/studies/doc/2013-06-03-contribution-to-impactassessment-of-measures-for-reducing-emissions-of-inland-navigation.pdf [accessed on 02.02.2016]
- 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
- STC-Nestra 2018 GHG emission factors for IWT. Final report, 2 May 2018. STC-NESTRA B.V., Rotterdam, The Netherlands. https://www.smartfreightcentre.org/pdf/GLEC-report-on-GHG-Emission-Factors-for-Inland-Waterways-Transport-SFC2018.pdf [accessed on 12.03.2021]

- Sustainable Shipping 2009 Emission Control Areas (ECAs) What you need to know. A Sustainable Shipping Briefing Paper, August 2009.
- Ligterink et al. 2019: Emissiefactoren wegverkeer Actualisatie 2019, TNO Report 2019 R10825v2
- 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. http://www3.epa.gov/ttnchie1/conference/ei17/session4/williams_pres.pdf [accessed on 01.02.2016]
- Yang, J., Johnson, K. C., Miller, J. W., Durbin, T. D., Karavalakis, G., Cocker, D. R. 2017: Marine Scrubber Efficiency and NOx Emission from Large Ocean Going Vessels. Presentation at the 2017 International Emissions Inventory Conference, August 14-18, Baltimore MD.

8.5 **Ferries**

- Bäckström 2003 Bäckström, S.: Internal description of the proposed NTM-methodology and comments to the proposal for EcoTransIT; February 2003
- Kristensen 2000 H.O. H. Kristensen (Danish Shipowners Association: Energy consumption and exhaust emissions for various types of marine transport compared with trucks and private cars; paper presented at ENSUS 2000 conference - newcastele 4-6 September 2000
- Kusche 2000 Kusche, J.: Transport-Ökobilanz von Deutschland nach Schweden: Diplomarbeit. Berlin 2000
- TT-Lines 2009 Internal values for energy consumption, capacity and load factor from TT Lines, 2009

8.6 Aircraft transport

- Airbus 2013 Airbus (Ed.): Future payloads freight forecast 2013 2032; Blagnac Cedex (France) 2013
- Atmosfair 2009 Atmosfair (Ed.): The atmosfair emission calculator. Methodological background. Berlin: 2009
- BEIS 2016 Department for Business, Energy and Industrial Strategy (DBEI): 2016 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors / Hill, N.; Watson, R. (Ricardo-AEA); James, K. (WRAP). Report on behalf of the for Business, Energy and Industrial Strategy (BEIS). London: 2016
- Cox & Althaus 2019 Cox, B and Althaus, H.J.: How to include non-CO2 climate change contributions of air travel at ETH Zurich. https://doi.org/10.3929/ethz-b-000409314
- EEA 2013/2015 EEA (European Environment Agency): EMEP/EEA Air pollutant emission inventory quidebook 2013. Technical quidance to prepare national emission inventories. EEA Technical report No 12/2013. Aviation annex (1.A.3.a) updated July 2015, Copenhagen: 2013/2015
- EEA 2019 EEA (European Environment Agency): 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, Copenhagen: 2019. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidancechapters/1-energy/1-a-combustion/1-a-3-a-aviation/at download/file [accessed 12.03.2021]
- **EUROCONTROL 2009** Astorino, A.: EUROCONTROL ETS Support Facilities and Fuel Estimator tool. Presentation. Brussels: 2009
- EUROCONTROL 2013a EUROCONTROL: Standard Inputs for EUROCONTROL Cost Benefit Analyses. Edition Number: 6.0. Edition Date: September 2013. Brussels: 2013
- EUROCONTROL: Small emitters tool: Version 5.05 dated 2015.12.26. Brussels: 2015

- EUROCONTROL: Small emitters tool: Version 5.07 dated 2017.11.22. Brussels: 2017
- EUROCONTROL: Small emitters tool: Version 5.09 dated 2019.11.29. Brussels: 2019. https://www.eurocontrol.int/publication/small-emitters-tool-set-2019 [accessed 12.03.2021)
- Hünecke 2008 Hünecke, K.: Die Technik des modernen Verkehrsflugzeuges. Stuttgart: Motorbuch Verlag 2008
- Graßl/Brockhagen 2007 Graßl, H; Brockhagen, D.: Climate forcing of aviation emissions in high altitudes and comparison of metrics. An update according to the Fourth Assessment Report, IPCC 2007, Hamburg: 2007
- IATA 2013 International Air Transport Association (IATA): Cargo e-Chartbook Q2 2013.
- ICAO 2012 International Civil Aviation Organisation (ICAO): ICAO Carbon Emissions Calculator. Version 5. Montreal: 2012
- ICAO 2018 Boubacar D. (ICAO): Overview of Air Cargo Services and Operations. Zhengzhou, 5.9.2018
- ifeu 2010 Knörr, W. (ifeu-Institut): EcoPassenger: Environmental Methodology and Data. Final Report. Commissioned by International Union of Railways (UIC). Heidelberg: 2010
- ifeu/Öko-Institut 2012: Knörr, W.; Schacht, A. (ifeu); Gores, S. (Öko-Institut); Entwicklung eines Modells zur Berechnung der Energieeinsätze und Emissionen des zivilen Flugverkehrs -TREMOD AV. UBA-Texte, No. 48/2012. Dessau: 2012
- IPCC 1999 Intergovernmental Panel on Climate Change (IPCC): 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. Cambridge: University Press, 1999.
- IPCC 2006 Intergovernmental Panel on Climate Change (IPCC): Datenbank für Emissionsfaktoren vom IPCC. 2006. See http://www.ipcc-nggip.iges.or.jp/EFDB/main.php.
- Knowler 2022 Knowler, Greg: Belly cargo capacity makes slow return to global air freight. The Journal of Commerce online, Jun 21, 2022
- Lang 2007 Lang, G.: Passagierflugzeuge Das aktuelle Typenbuch. München: Scont-Verlag, 2007
- Lang 2009 Lang, G.: Flugzeuge Die bekanntesten Passagierflugzeuge der Welt. Fränkisch-Crumbach: Edition XXL, 2009
- Lee et al 2020: Lee D. S., Fahey D. W., Skowron A., Allen M. R., Burkhardt U., Chen Q., Doherty S. J., Freeman S., Forster P. M., Fuglestvedt J., Gettelman A., DeLeon R. R., Lim L. L., Lund M. T., Millar R. J., Owen B., Penner J. E., Pitari G., Prather M. J., Sausen R. and Wilcox L. J. (2020), The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018
- Lufthansa 2014 Deutsche Lufthansa AG (Ed.): Geschäftsbericht 2013. Frankfurt/M.: 2014.
- LCAG 2014 Lufthansa Cargo (Ed.): Pallets, Container and Fleet. Frankfurt/M.: 2014
- Öko-Institut 2009 Graichen, J.; Gores, S.; Herold, A.: Überarbeitung des Emissionsinventars des Flugverkehrs. Final report on behalf of the Umweltbundesamtes. Berlin: 2009
- Piano 2008 Pianox: Aircraft Emissions and Performance User's Guide. Woodhouse Eaves (UK): 2008
- Statista 2018: Freight-ton kilometers of main cargo aircraft and aircraft with combined passenger and freight capacity as a share of world total in 2016 and 2036. Accessed 4.12.2018
- Statista 2022: Freight-ton kilometers share of air cargo traffic worldwide in 2019 by type. Accessed Nov. 10. 2022
- UBA 2008 Umweltbundesamt (2008): Klimawirksamkeit des Flugverkehrs. Aktueller wissenschaftlicher Kenntnisstand über die Effekte des Flugverkehrs. Dessau: März 2008.
- Whelan 2022 Whelan, Sam: Full bellies again for air cargo, but some players still hungry for freighters. The loadstar. 30.6.2022

8.7 Energy supply and biofuel shares

BREF 2015 Barthe, P., Chaugny, M., Roudier, S., 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).

http://eippcb.irc.ec.europa.eu/reference/BREF/REF BREF 2015.pdf

- Bussa 2021 Bussa, M.; Jungbluth, N.; Meili, C. (2021): Life cycle inventories for long-distance transport and distribution of natural gas.
- ISO 14083 Greenhouse gases Quantification and reporting of greenhouse gas emissions arising from transport chain operations. FDIS 2020
- EN 16258 "Methode zur Berechnung und Deklaration des Energieverbrauchs und der Treibhausgasemissionen bei Transportdienstleistungen (Güter- und Personenverkehr)" 2013
- Eurostat 2015 Yearly Energy Statistics 2013 data
- ICAO 2021 International Civil Aviation Organisation (ICAO): CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels

https://www.icao.int/environmental-

protection/CORSIA/Documents/ICAO%20document%2006%20-

%20Default%20Life%20Cvcle%20Emissions%20-%20March%202021.pdf

- IEA 2015 IEA Energy Statistics 2013 data
- ifeu 2016 Fehrenbach et al. (ifeu): Aktualisierung der Eingangsdaten und Emissionsbilanzen wesentlicher biogener Energienutzungspfade (BioEm), 2016
- ifeu 2018 Fehrenbach H., Liebich A., Abdalla N., Biemann K., Fröhlich T., Simon B., (2018). Life Cycle Inventories of Petroleum Refinery Operation. ecoinvent Association, Zürich, Switzerland.
- Jackson 2020 Jackson, R. B.; Saunois, M.; Bousquet, P.; Canadell, J. G.; Poulter, B.; Stavert, A. R.; Bergamaschi, P.; Niwa, Y.; Segers, A.; Tsuruta, A. (2020): Increasing anthropogenic me-thane emissions arise equally from agricultural and fossil fuel sources. In: Environmental Research Letters. IOP Publishing. Vol. 15, No. 7, S. 071002.
- JEC Well-To-Wheels report v5 Prussi, M., Yugo, M., De Prada, L., Padella, M., Edwards. JEC Well-To-Wheels report v5. EUR 30284 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-20109-0, doi:10.2760/100379, JRC121213...
- UNEP 2016 Partnership for Clean Fuels and Vehicles Diesel Fuel Sulphur Levels: Global Status January 2016; http://www.unep.org/transport/new/pcfv/about.asp last visit April, 2016
- Directive 2004/8/EC Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC
- ecoinvent v 3.8: Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230.
- Meili 2021 Meili, C.; Jungbluth, N.; Maresa Bussa (2021): Life cycle inventories of crude oil and natural gas extraction.
- Meyers 2003 Robert A. Meyers (ed.): Handbook of Petroleum Refining Processes, 3rd edition. 2003

- Saunois 2020 Saunois, M.; Stavert, A. R.; Poulter, B.; Bousquet, P.; Canadell, J. G.; Jackson, R. B.; Raymond, P. A.; Dlugokencky, E. J.; Houweling, S.; Patra, P. K.; Ciais, P.; Arora, V. K.; Bastviken, D.; Bergamaschi, P.; Blake, D. R.; Brailsford, G.; Bruhwiler, L.; Carlson, K. M.; Carrol, M.; Castaldi, S.; Chandra, N.; Crevoisier, C.; Crill, P. M.; Covey, K.; Curry, C. L.; Etiope, G.; Frankenberg, C.; Gedney, N.; Hegglin, M. I.; Höglund-Isaksson, L.; Hugelius, G.; Ishizawa, M.; Ito, A.; Janssens-Maenhout, G.; Jensen, K. M.; Joos, F.; Kleinen, T.; Krummel, P. B.: Langenfelds, R. L.: Laruelle, G. G.: Liu, L.: Machida, T.: Maksyutov, S.: McDonald, K. C.: McNorton, J.; Miller, P. A.; Melton, J. R.; Morino, I.; Müller, J.; Murguia-Flores, F.; Naik, V.; Niwa, Y.; Noce, S.; O'Doherty, S.; Parker, R. J.; Peng, C.; Peng, S.; Peters, G. P.; Prigent, C.; Prinn, R.; Ramonet, M.; Regnier, P.; Riley, W. J.; Rosentreter, J. A.; Segers, A.; Simpson, I. J.; Shi, H.; Smith, S. J.; Steele, L. P.; Thornton, B. F.; Tian, H.; Tohjima, Y.; Tubiello, F. N.; Tsuruta, A.; Viovy, N.; Voulgarakis, A.; Weber, T. S.; van Weele, M.; van der Werf, G. R.; Weiss, R. F.; Worthy, D.; Wunch, D.; Yin, Y.; Yoshida, Y.; Zhang, W.; Zhang, Z.; Zhao, Y.; Zheng, B.; Zhu, Q.; Zhu, Q.; Zhuang, Q. (2020): The Global Methane Budget 2000–2017. In: Earth System Science Data. Copernicus GmbH. Vol. 12, No. 3, S. 1561–1623.
- Eurostat 2020 Yearly Energy Statistics 2018 data "Final energy consumption in road transport by type of fuel: Gas oil and diesel oil (excluding biofuel portion) + Blended biodiesels + Natural gas + Biogases"
- UN database 2020 Energy Statistics Database 2017 data
- GREET 2021 Wang, Michael, Elgowainy, Amgad, Lee, Uisung, Baek, Kwang H., Bafana, Adarsh, Benavides, Pahola T., Burnham, Andrew, Cai, Hao, Cappello, Vincenzo, Chen, Peter, Gan, Yu, Gracida-Alvarez, Ulises R., Hawkins, Troy R., Iyer, Rakesh K., Kelly, Jarod C., Kim, Taemin, Kumar, Shishir, Kwon, Hoyoung, Lee, Kyuha, Liu, Xinyu, Lu, Zifeng, Masum, Farhad, Ng, Clarence, Ou, Longwen, Reddi, Krishna, Siddique, Nazib, Sun, Pingping, Vyawahare, Pradeep, Xu, Hui, and Zaimes, George. Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model ® (2022 Excel). Computer Software. USDOE Office of Energy Efficiency and Renewable Energy (EERE). 10 Oct. 2022. Web. doi:10.11578/GREET-Excel-2022/dc.20220908.1.

Cooled transports 8.8

- 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. Institut für Energie- und Umweltforschung Heidelberg. Im Auftrag des Umweltbundesamtes. April, 2015.
- Kranke, A. / Schmied, M. / Schön, A. D. 2011 CO2-Berechnung in der Logistik Datenguellen, Formeln, Standards. Verlag Heinrich Vogel.
- Tassou, S. A. / De-Lille, G. / Ge, Y. T. 2009 Food transport refrigeration Approaches to reduce energy consumption and environmental impacts of road transport. In: Applied Thermal Engineering. Vol. 29, No.8–9, pp. 1467–1477.
- ThermoKing 2014 https://www.thermoking.com/news-article.aspx?id=396
- Fitzgerald, Warren & J.A. Howitt, Oliver & J. Smith, Inga & Hume, Anthony. (2011). Energy use of integral refrigerated containers in maritime transportation. Energy Policy. 39. 1885-1896. 10.1016/j.enpol.2010.12.015.
- Weidema, B. P. / Bauer, C. / Hischier, R. / Mutel, C. / Nemecek, T. / Reinhard, J. / Vadenbo, C. O. / Wernet, G. 2013 The ecoinvent database: Overview and methodology, Data quality guideline for the ecoinvent database version 3. Ecoinvent Center, Zürich. www.ecoinvent.org.

Expressions and abbreviations 9

Gtkm	Gross tonne kilometre hauled	Tonne kilometre of freight including empty wagon (vehicle, vessel) weight; for railways: train without locomotive
Ntkm	Net tonne kilometre:	Tonne kilometre of freight; also: tkm
tkm	Tonne kilometre	Tonne kilometre of freight; also: Ntkm (in distinction to Gtkm)
Gt	Gross tonnes t	Tonnes of freight including empty wagon (vehicle, vessel) weight; for railways: train without locomotive
Nt	Net tonnes	Tonnes of freight
T	Tonne	Metric tonne, unit used in ETW for the freight mass
RFI	Radiative Forcing Index	Takes into account the climate effects of other GHG emissions (in particular nitrogen oxides, ozone, water, soot, sulphur), especially for emissions in high altitudes. (>9km)
	Payload	Load weight of freight
CP	Payload capacity	Mass related capacity of a vehicle/vessel for freight
LF	Load factor	Relation of net tonnes and tonne capacity of a vehicle/vessel without empty trip factor
CU	Capacity utilisation	Relation of net tonnes and tonne capacity of a vehicle/vessel including the empty trip factor
ET	Empty trip factor	Relation of vehicle/vessel-km running empty and km loaded
D	Distance	Transport distance in km
Km	Kilometre	
М	Mass of freight	
EC	Energy consumption	
ECT	Total energy consumption	Sum of final energy consumption and upstream energy consumption
ECF	Final energy consumption	Energy consumption of vehicle/vessel
ECU	Upstream energy consumption	Energy consumption for production and delivery of final energy
EGR	Exhaust Gas Recirculation	Technology to reduce emissions of diesel engines
EMT	Total emissions	Sum of vehicle and upstream emissions
EMV	Emissions vehicle	Direct emissions from vehicle operation
EMU	Upstream Emissions	Emissions of upstream process
HFO	Heavy fuel oil	Fuel for marine vessels
MDO	Marine diesel oil	
MGO	Marine Gas oil	
SCR	Selective Catalytic Reduction	Technology to reduce emissions of diesel engines
TEU	Twenty-foot equivalent	Unit for container transport
FEU	Forty-foot equivalent	Unit for container transport
TTW	Tank-to Wheels	Energy consumption and emissions from vehicle operation, called operational GHG emissions in ISO 14083
WTT	Well-to-Tank	Energy consumption and emissions from upstream processes
WTW	Well-to-Wheels	Energy consumption and emissions from vehicle operation and upstream processes, called total GHG emissions in ISO 14083

* See Disclaimer