

EcoTransIT World

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# Environmental Methodology and Data Update 2022

*commissioned by*  
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## 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; it follows 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 40 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.

# 1 Introduction

## 1.1 Background and task

As freight transport mainly relies on conventional energy carriers like diesel, kerosene and heavy fuel oil, it significantly contributes to major challenges of the 21<sup>st</sup> 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 (CO<sub>2</sub>), sum of all greenhouse gases (measured as CO<sub>2</sub> equivalents) and air pollutants, such as

nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), non-methane hydro carbons (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

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 CO<sub>2</sub> 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 CO<sub>2</sub> equivalent emissions (kg CO<sub>2e</sub>) 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 CO<sub>2e</sub>/litre diesel). ETW uses the conversion factors for fuels included in EN 16258 without changes (see chapter 7.1 in the annex of this report). 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 (see chapter 6.6).

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 ifeu 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. One example of this brief declaration is given in the annex of this report (see chapter 0).

**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 CO<sub>2</sub> 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 1<sup>st</sup> of October 2013 at the latest, CO<sub>2</sub>e 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.



## 2 ETW business solutions

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 SO<sub>x</sub> based on Clean Cargo trade lane emission factors
  - o adjustable allocation factor (default 70%) and flexible distance correction factor (default 15%)
  - o sophisticated trade lane mapping
  - o usage of SCAC based emission factors (only for Clean Cargo members)



- Automatically flight number analyses via OAG.com interface:
  - enables appliance of an aircraft share via flight 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 transshipment processes via the REff Tool® (<https://reff.iml.fraunhofer.de/>) and  Fraunhofer IML's methodology<sup>1</sup>
- 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.

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<sup>1</sup> 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/.

### 2.1.1 Methodology support included

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

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.

## 2.2 Available Interfaces (API)

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.

## 2.3 Calculation Service

In addition to the API, the IVE mbH team offers to calculate, analyse and present customer-specific 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.

### 3.1 Transport service and vehicle operation system

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 <sub>2</sub>	Carbon dioxide emissions	Main indicator for greenhouse effect
CO <sub>2e</sub>	Greenhouse gas emissions as CO <sub>2</sub> -equivalent. CO <sub>2e</sub> is calculated as follows (mass weighted): $CO_{2e} = CO_2 + 25 * CH_4 + 298 * N_2O$ CH <sub>4</sub> : Methane N <sub>2</sub> O: Nitrous Oxide	Greenhouse effect
NO <sub>x</sub>	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
SO <sub>2</sub>	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 energy consumption and GHG emissions measured as CO<sub>2</sub> equivalents can be calculated with ETW. The definitions used by ETW are similar to the definitions of EN 16258.

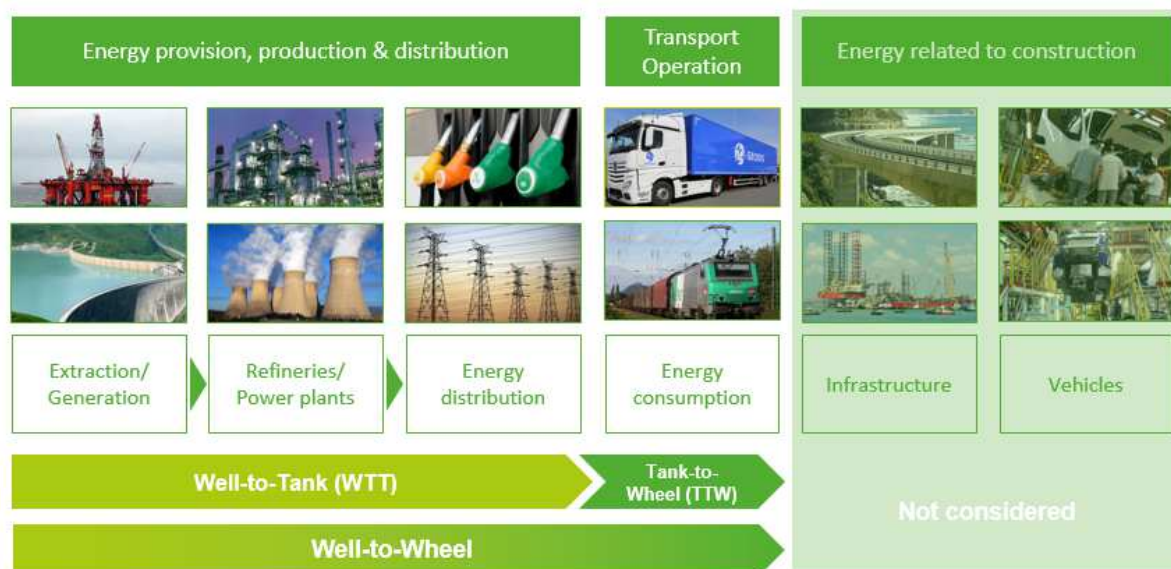
### 3.3 System boundaries of processes

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 new 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

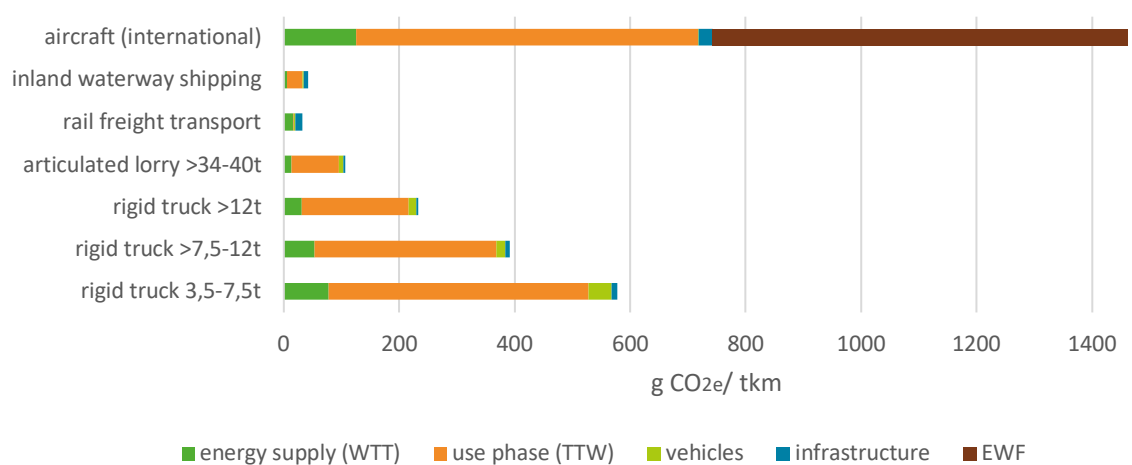
The EN 16258 follows a Well-to- wheels approach and thus does not include the transport infrastructure (streets, railways...) and the vehicles used for transport (e.g. manufacturing, maintenance and end-of-life for trucks, airplanes, trains and ships).

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

\*\* 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.

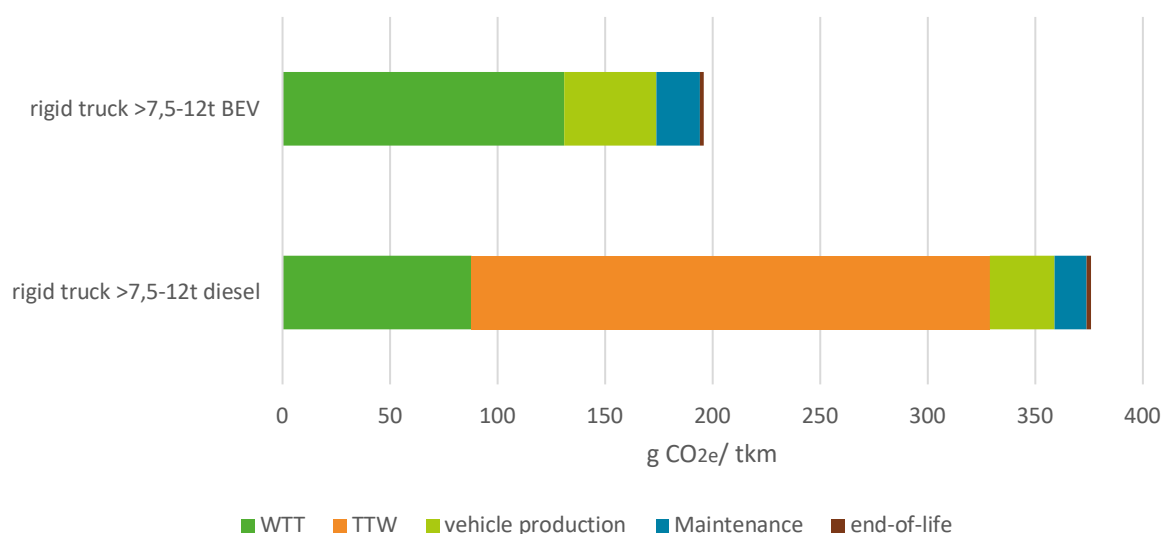
More relevant are the contributions from the particulate emissions. In recent years, direct particulate emissions at the vehicle exhaust level have decreased greatly, leading to a higher contribution of the WTT part of the process chain and the emissions from vehicles and infrastructure.

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 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<sub>2e</sub> 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 fuelled 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.

Table 2 Transport modes, vehicles and propulsion systems

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

### 3.5 Spatial differentiation

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 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.

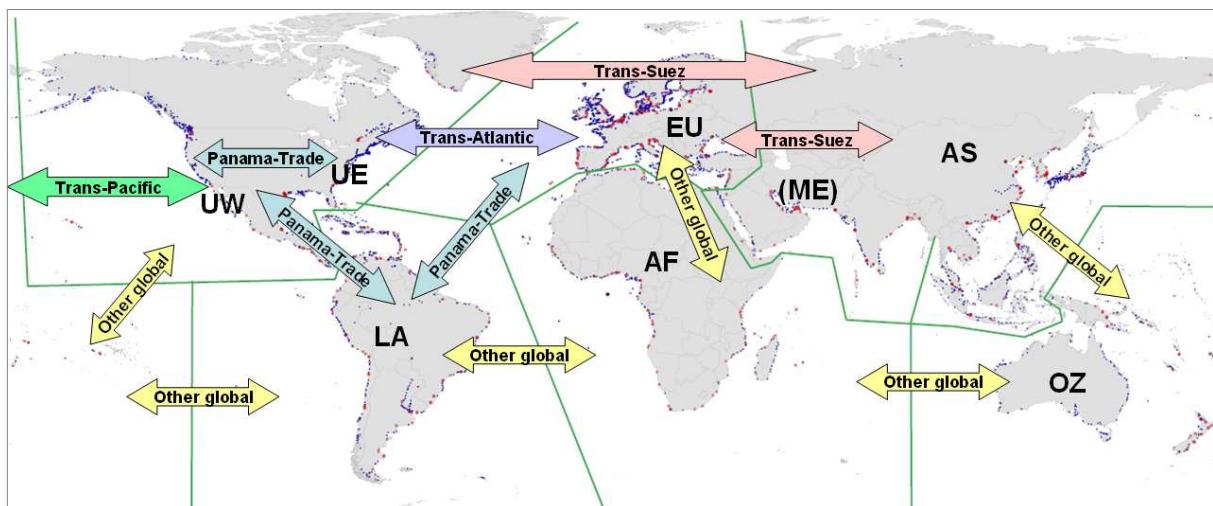
Differences may exist for railway transport, where the various railway companies employ different locomotives and train configurations. However, the observed differences in the average energy consumption are not significant enough to be established statistically with certainty. Furthermore, within the 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

	<b>Country/region specific parameter</b>	<b>Mode specific parameter</b>
<b>Road</b>	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
<b>Rail</b>	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
<b>Inland Ship</b>	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
<b>Sea Ship</b>	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
<b>Aircraft</b>		Aircraft type: - Final energy consumption (TTW) - Emission factors (TTW): NOx, NMHC, PM - Design range
	<b>Fuel dependent values</b>	
<b>All Modes</b>	Energy conversion factors (WTT and TTW) from EN 16258 CO <sub>2</sub> e-conversion factors (WTT and TTW) from EN 16258 CO <sub>2</sub> -conversion factors (WTT and TTW) compatible with EN 16258 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 <sub>2</sub> , CO <sub>2</sub> e, NOx, NMHC, PM	

## 4 Basic definitions and calculation rules

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.

### 4.1 Main factors of influence on energy and emissions of 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 CO<sub>2e</sub> 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, Vessel	Type, size, payload capacity	E	E	E	E	E
	Drive, energy	E	E	A	A	A
	Technical and emission standard	E	E	A	E	A
Traffic route	Road category, waterway class	R			R	
	Gradient, water/wind resistance	A	A	A	A	A
Driving Conditions	Speed	A	A	E	A	A
	No. of stops, acceleration	A	A	A	A	A
	Length of LTO/cruise cycle					R
Transport Logistic	Load factor	E	E	E	E	E
	Empty trips	E	E	E	E	E
	Cargo specification	S	S	S	S	S
	Intermodal transfer	E	E	E	E	E
	Trade-lane specific vessels			R		
Transport Work	Cargo mass	S	S	S	S	S
	Distance travelled	R	R	R	R	R
Remarks:						
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						

## 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

kg/m<sup>3</sup> 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 EcoTransIT World, 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 net-weight 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.

	<b>L*W*H [m]</b>	<b>Volume [m<sup>3</sup>]</b>	<b>Empty weight</b>	<b>Payload capacity</b>	<b>Total weight</b>
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 Ship	Neo K (class IV) N/A in ETW	110	650		
	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 (only Freighter)	Boeing 737-300SF	43.6	19.7	-	63.3
	Boeing 767-300F	86.5	53.7	-	140.2
	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
M	Mass of freight	[net tonne]
CP	Payload capacity	[tonnes]
LF <sub>NC</sub>	Load Factor: mass of weight / payload capacity $LF_{NC} = M / CP$	[net tonnes/tonne capacity]; [%]
ET	Empty trip factor: Additional related to loaded distance allocated to the transport. $ET = \text{Distance empty} / \text{Distance loaded}$	[km empty/km loaded], [%]

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

Abbr.	Definition/Formula	Unit
CU <sub>NC</sub>	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 <sub>NC</sub>	Capacity utilisation	[%]
Abbr.	Formula	
CU <sub>NG</sub>	Net-gross relation = capacity utilisation / (capacity utilisation + empty wagon weight / mass capacity wagon). $CU_{NG} = CU_{NC} / (CU_{NC} + EW/CP)$	[net tonnes/gross tonnes]

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 vehicle-km 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 7.3.

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.

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

	Load factor LF <sub>NC</sub>	Empty trip factor ET	Capacity utilisation CU <sub>NC</sub>	Relation Nt/Gt CU <sub>NG</sub>
<b>Train wagon</b>				
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
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
<b>Truck</b>				
Bulk	100%	60%	63%	
Average	60%	20%	50%	
Volume	30%	10%	27%	
Source: DB Cargo, SNCF Geodis, ifeu estimations				

### 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

$$LF_{\text{Truck}} = (\text{Container}_{\text{brutto}} * \text{Container amount}_{\text{vehicle}}) / \text{payload capacity}_{\text{truck}}$$

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

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

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%
Note: BC = bulk carrier, GC = general cargo, CC = container cargo vessel. Sources: IMO 2009; Seum 2010; Scandria 2012; CCWG 2014		

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 CO<sub>2</sub> emission values of the container ships considering real utilisation factors /CCWG 2014/.

Figure 6: Sample Asia North America Trade Lane by Hapag Lloyd AG<sup>2</sup>



### 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.

<sup>2</sup> Internet Site from 01/10/2014.

## 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 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

	<b>Freight</b> (freighters and passenger aircrafts)	<b>Passenger</b> (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

$$\begin{aligned} & \text{Final energy consumption per net tonne km} = \\ & * \text{specific energy consumption of vehicle or vessel per km} \\ & / (\text{payload capacity of vehicle or vessel} * \text{capacity utilisation of vehicle or vessel}) \end{aligned}$$

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 principal calculation rule for the calculation of energy related vehicle emissions is

$$\begin{aligned} & \text{TTW Vehicle emissions per net tonne-km} = \\ & \text{specific energy consumption of vehicle or vessel per net tonne km} \\ & * \text{energy related vehicle emission factor per energy carrier} \end{aligned}$$

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 CO<sub>2</sub> and SO<sub>2</sub> emissions) and for combustion related emissions of fuel driven trains and ships (see chapter 6.2 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 EN 16258 the energy factors of the European standard EN 16258 are used by ETW (see chapter 7.1 in the annex).
- Based on the European standard the CO<sub>2</sub> equivalents are also calculated by multiplication of the TTW energy consumption with energy related TTW emission factors (e.g., kg CO<sub>2</sub>e per litre diesel). For this calculation step the emission factors respectively conversion factors of the European standard EN 16258 are used without changes. The used values are documented in chapter 7.1 in the annex).
- The CO<sub>2</sub> emission factors used by ETW (e.g., kg CO<sub>2</sub>/litre diesel) are based on the same sources like the CO<sub>2</sub> equivalent emission factors included in the European standard EN 16258. Therefore, CO<sub>2</sub> emission quantifications can't be in accordance with EN 16258 since only CO<sub>2</sub> equivalent calculations are required by European standard. Nevertheless, ETW allows the calculation of CO<sub>2</sub> emissions based on the same methodology and the same data sources as the European standard EN 16258.

### 4.3.3 Combustion related emissions per net tonne km (TTW)

The principal **calculation rule** for the calculation of TTW NO<sub>x</sub>, NMHC and particles emissions (so called combustion related emissions) is

$$\begin{aligned} & \text{TTW Emissions per net tonne km} = \\ & \quad * \text{ specific emission factor of vehicle or vessel per km} \\ & \quad / (\text{payload capacity of vehicle or vessel} * \text{capacity utilisation of vehicle or vessel}) \end{aligned}$$

The corresponding **formula** is

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

Abbr.	Definition	Unit
EMV <sub>tkm,i</sub>	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 <sub>km,i</sub>	Combustion related vehicle emission factor (TTW) of vehicle or vessel per km; normally depends on mass related capacity utilisation	[g/km]
CP	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

$$\begin{aligned} & \text{WTT Upstream energy consumption or emissions per net tonne-km} = \\ & \quad \text{specific energy consumption of vehicle or vessel per net tonne km} \\ & \quad * \text{ energy related upstream energy or emission factor per energy carrier} \end{aligned}$$

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 <sub>tkm,i</sub>	Upstream emissions (WTT) for each energy carrier i	[g/tkm]
ECU <sub>tkm,i</sub>	Upstream energy consumption (WTT) for each energy carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HS)	
ECF <sub>tkm,i</sub>	Final energy consumption (TTW) per net tonne km for each energy carrier i	[MJ/tkm]
EMU <sub>EC,i</sub>	Energy related upstream emission factor (WTT) for each energy carrier i	[g/MJ]
ECU <sub>EC,i</sub>	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 6.6.
- For the calculation of WTT energy and WTT CO<sub>2</sub> equivalent the emission factors of the new European standard are used for ETW. Only for electricity EN 16258 doesn't provide emission factors. Therefore, ETW calculates own emission factors for electricity in accordance to the European standard. The methodology as well as used values is documented in the chapters 6.6 and 7.1.

### 4.3.5 Total energy consumption and emissions of transport (WTW)

The principal calculation rule for the calculation of vehicle emissions is

$$\begin{aligned} & \text{WTW energy consumption or emissions per transport} = \\ & \quad \text{Transport Distance} \\ & \quad * \text{mass of freight transported} \\ & * (\text{TTW energy consumption or vehicle emissions per net tonne km} \\ & \quad + \text{WTT energy consumption or emissions per net tonne km}) \end{aligned}$$

The corresponding formulas are

$$\text{EMT}_i = D_i * M * (\text{EMV}_{tkm,i} + \text{EMU}_{tkm,i})$$

$$\text{ECT}_i = D_i * M * (\text{ECF}_{tkm,i} + \text{ECU}_{tkm,i})$$

Abbr.	Definition	Unit
EMT <sub>i</sub>	WTW emissions of transport	[kg]
ECT <sub>i</sub>	WTW energy consumption of transport	[MJ]
D <sub>i</sub>	Distance of transport performed for each energy carrier i	[km]
M	Mass of freight transported	[net tonne]
EMV <sub>tkm,i</sub>	TTW Vehicle emissions for each energy carrier i	[g/tkm]
ECF <sub>tkm,i</sub>	TTW energy consumption for each energy carrier i	[MJ/tkm]
EMU <sub>tkm,i</sub>	WTT (upstream) emission factors for each energy carrier i	[g/tkm]
ECU <sub>tkm,i</sub>	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 CO<sub>2</sub> 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) CO<sub>2</sub> 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	Type	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	Type	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 city-street 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.

Table 16 Resistance for ferries in the railway network

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-ports<sup>3</sup>, 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.

Figure 9 Sea network around Denmark /IVE 2019/



<sup>3</sup> 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.

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) 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:

$$\text{Real flight distance} = \text{GCD} + 95 \text{ km}$$

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.

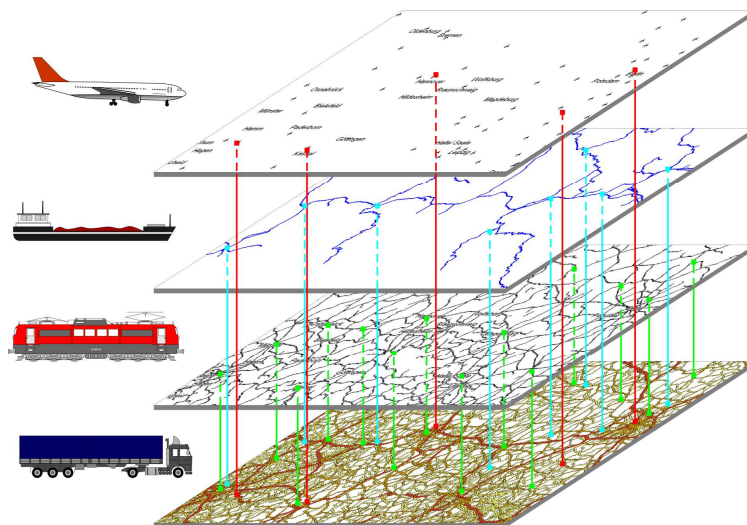
## 5.5 Determination of transport points within combined transport chains

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

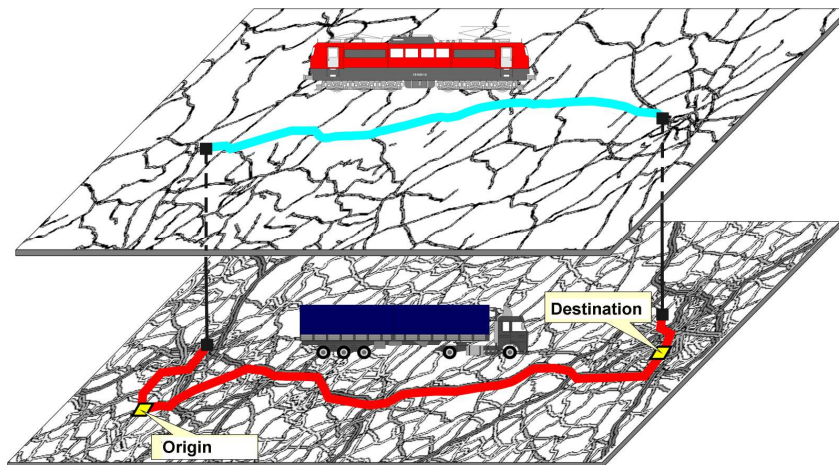
selection of the transfer points is also influenced by the size range of the respective airport or harbour. Thus, a container-based Suez trade will always start and end with a large classified harbour or a medium haul flight needs at least medium classified airports.

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 CO<sub>2</sub> 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

\* 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 2019/ 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 2019/. 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**. Similar to rail transport, 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 4.1) /INFRAS 2019/ for trucks with Euro standards. For the determination of values for trucks in North America several sources were analysed:

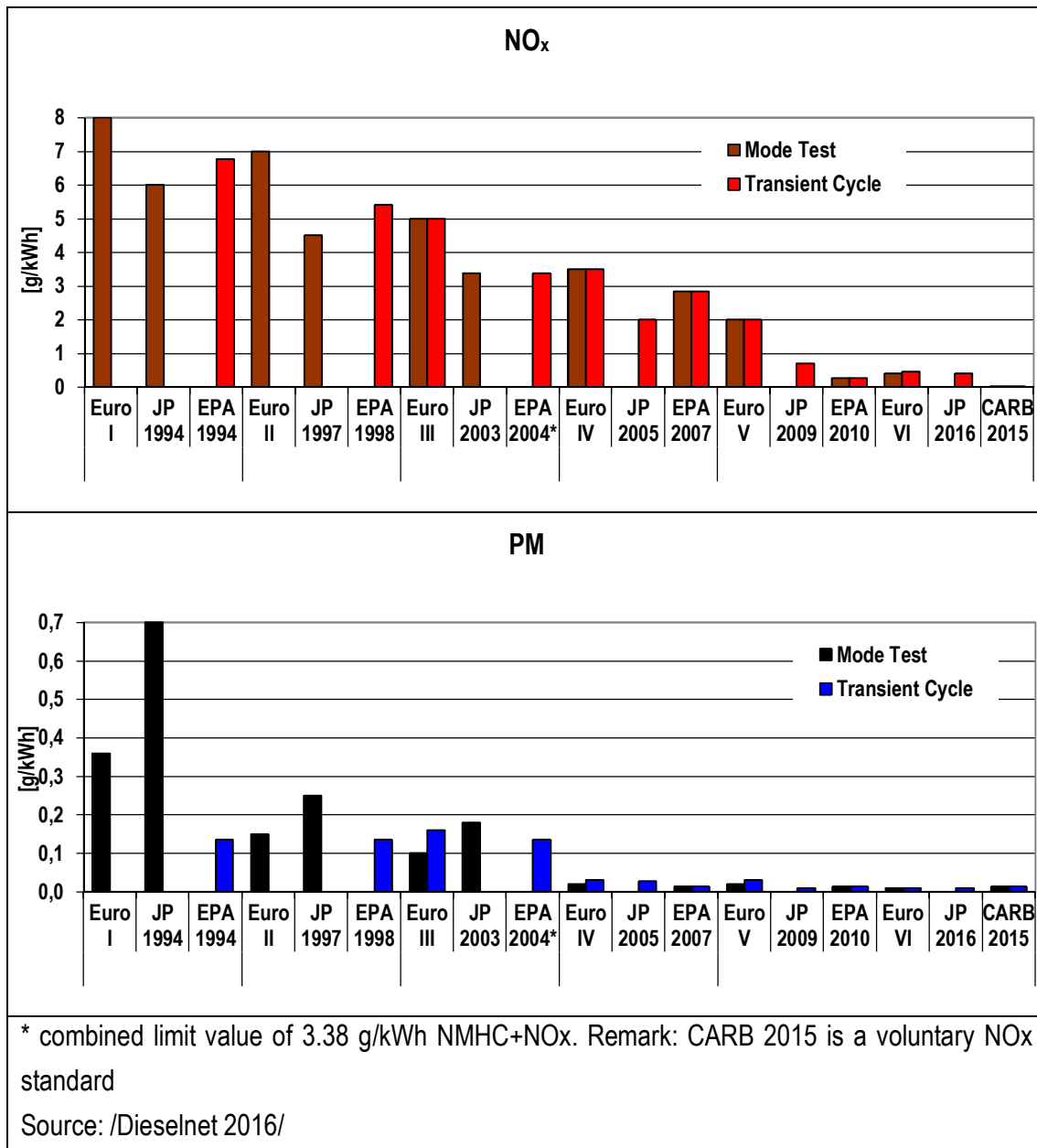
- emission limit values for the EPA standard compared with the EU standard /Dieselnet 2014/
- the emission model MOVES2014 to compare emission factors and energy consumption of trucks by road type, registration year and size /EPA 2014/
- further statistical data (/USCB 2004/, /USDOT 2007/, /USDOE 2009/)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

Figure 12 EU, Japanese and U.S. Emission Limit Values for Heavy Duty Diesel Vehicles by Emission Standard 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 SO<sub>2</sub> 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
<b>Africa</b>	AFR	5000	EURO II	-
	ZA	500	EURO II	-
<b>Asia and Pacific</b>	ASP	5000	EURO II	-
	CN	50	EURO III	EURO IV
	HK	10	EURO IV	EURO V
	IN	350	EURO II	EURO III
	JP	10	JP 2009	JP 2016
	IR	8000	EURO II	-
	KR	50	EURO IV	EURO IV
<b>Australia</b>	AU	10	EURO V	EURO V
<b>Middle East</b>	MIE	5000	EURO II	-
<b>World</b>	WRLD	5000	EURO II	-
<b>Central and South America</b>	CSA	5000	EURO II	-
	BR	500	EURO III	EURO V
	CL	15	EURO III	EURO V
	MX	500	EURO III	EURO IV
<b>Europe</b>	EUR	500	EURO II	-
	BA	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
	CH	10	EURO VI	EURO VI
	IL	10	EURO V	EURO V
<b>North America</b>	CA	15	EPA 2010	CARB 2015
	US	15	EPA 2010	CARB 2015
<b>Russia and FSU</b>	FSU 15	500	EURO II	-
	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/; dieselnets.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 GVW 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
<b>Africa</b>	afr	Truck >20-26t
	ZA	Truck >20-26t
<b>Asia and Pacific</b>	asp	Truck >12-20t
	CN	Truck >20-26t
	HK	Truck >20-26t
	IN	Truck >20-26t
	JP	Truck >20-26t
	IR	Truck >12-20t
	KR	Truck >12-20t
<b>Australia</b>	AU	Truck >26-40t
<b>Middle East</b>	MIE	Truck >20-26t
<b>World</b>	Wrld	Truck >26-40t
<b>Central and</b>	csa	Truck >12-20t

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

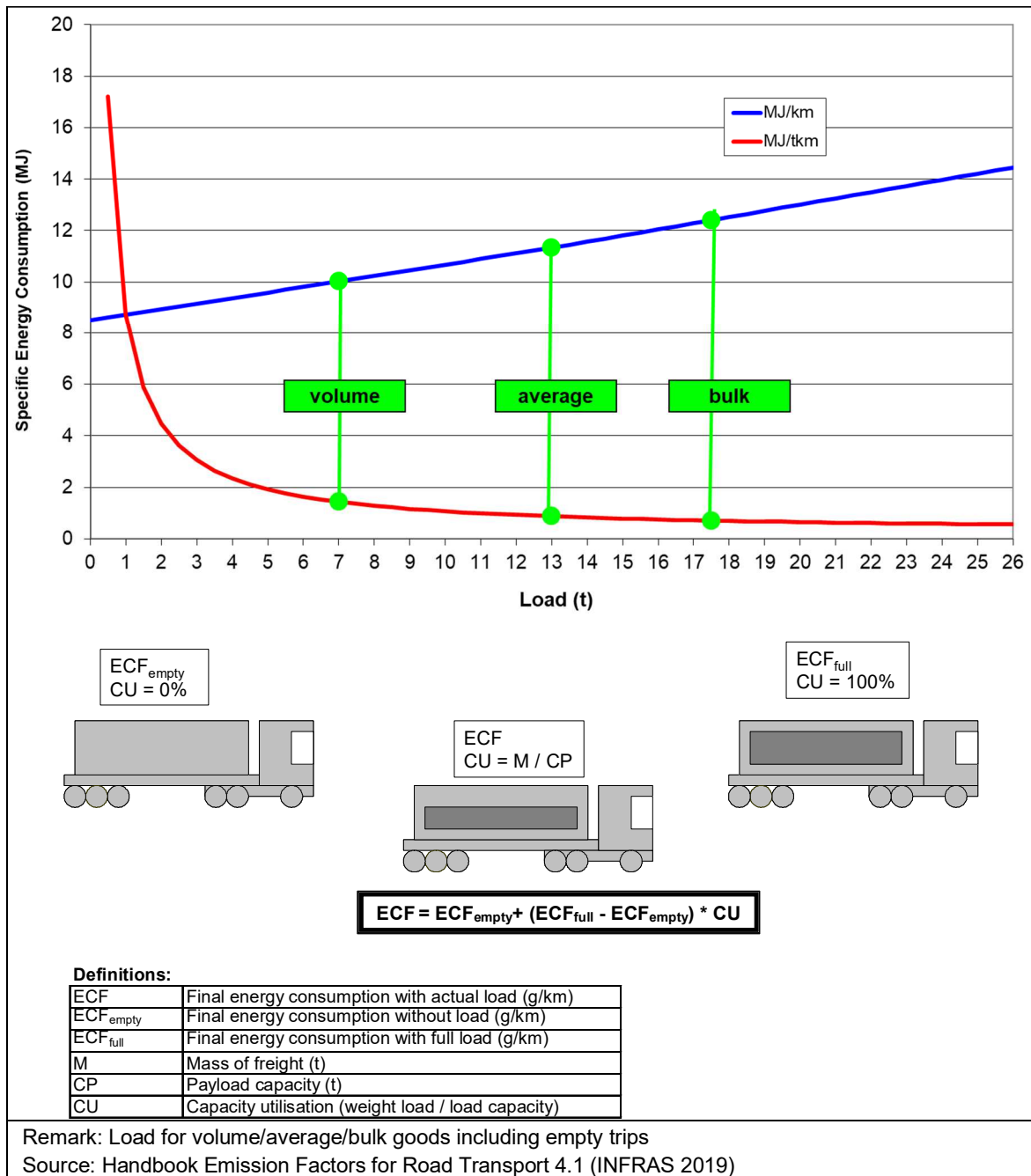
### 6.1.3 Final energy consumption and vehicle emissions (TTW)

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.

Figure 13: Energy consumption for heavy duty trucks (40 t vehicle gross weight, Euro-V, motorway, hilly) 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 CO<sub>2</sub>- and CO<sub>2e</sub>-emissions the default values of EN 16258 are applied (see Table 57 in the appendix, chapter 7.1)

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

Vehicle Type		empty 0%	Average* 60%	full 100%
<b>Energy Consumption (MJ/km)</b>				
Truck Euro VI	>3,5-7,5t	6,1	6,7	7,1
	>7,5-12t	6,5	7,3	7,8
	>12-20t	7,2	8,7	9,7
	>20-26t	7,8	9,8	11,2
	>26-40t	8,5	11,9	14,4
	>40-50t	9,3	13,9	17,2
	>50-60t	11,5	16,8	20,4
	>60t	15,0	23,3	29,3
<b>NOx-Emissions (g/km)</b>				
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	2,4	2,6	2,8
	Euro-VI	0,6	0,4	0,5
<b>NMHC-Emissions (g/km)</b>				
Truck >26-40t	Euro-I	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	0,015	0,019	0,023
<b>PM-Emissions (g/km)</b>				
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	0,010	0,009	0,009
Source: Handbook Emission Factors for Road Transport 4.1 (INFRAS 2019)				
*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 4.1 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 with 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 GV) 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 countries<sup>4</sup>. 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 km<sup>2</sup>. 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](http://www.gibgas.de) for the EU or [www.afdc.energy.gov](http://www.afdc.energy.gov) for the USA.

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<sup>4</sup> 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 km<sup>2</sup>)

Fuel	Region	Country	Stations	Stations per 1000 km <sup>2</sup>
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
	Europe	Germany	3	0.01
	North America	United States	76	0.01

Source: EU: NGVA, 2017 data; Non-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 (NO<sub>x</sub>, 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 SO<sub>x</sub> 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

Vehicle Type (fuel, size, emission standard)	EC	NO <sub>x</sub>	NMHC	PM
CNG, all size classes, Euro V	+24%	similar		Euro VI
CNG, all size classes, Euro VI	+24%	similar		
LNG, all size classes, Euro V	+24%	similar		Euro VI
LNG, all size classes, Euro VI	+24%	similar		
Dual Fuel (LNG/Diesel), all size classes, Euro V		similar		

Source: (DLR et al. 2015), ifeu assumptions

Integration of gas-powered trucks into HBEFA 4.1 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 integrated into the HBEFA 4.1. 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 battery- electric trucks provide a range of 350 km and have a higher empty weight than their conventional counterparts due to the addition of the battery.

Table 27 TTW energy consumption of electric trucks

Size Class	Empty 0%	Average 60%	Full 100%
Truck <7.5t	2,7	3,0	3,2
Truck 7.5-12t	2,9	3,2	3,4
Truck 12-20t	3,3	3,6	3,8
Truck 26-40t	5,3	6,2	6,7

Source: Handbook Emission Factors for Road Transport 4.1 (INFRAS 2019)

## 6.2 Rail transport

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.

Table 28 Definition of general train types in ETW

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

Source: ETW definitions and assumptions
---

### 6.2.3 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.

Table 29 Definition of dedicated train types in ETW

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 energy functions are used, which are verified by average values from different European railways. To take the different topologies of the European countries into account, three types of functions are used, which shall represent a “flat” (Denmark, Netherlands, Sweden), “mountain” (Austria, Switzerland) or “hilly” (all other countries) topology. For ETW, the function was updated with new values and a special survey for heavy trains (>2,000 tonnes).

The following energy consumption data for trains were available:

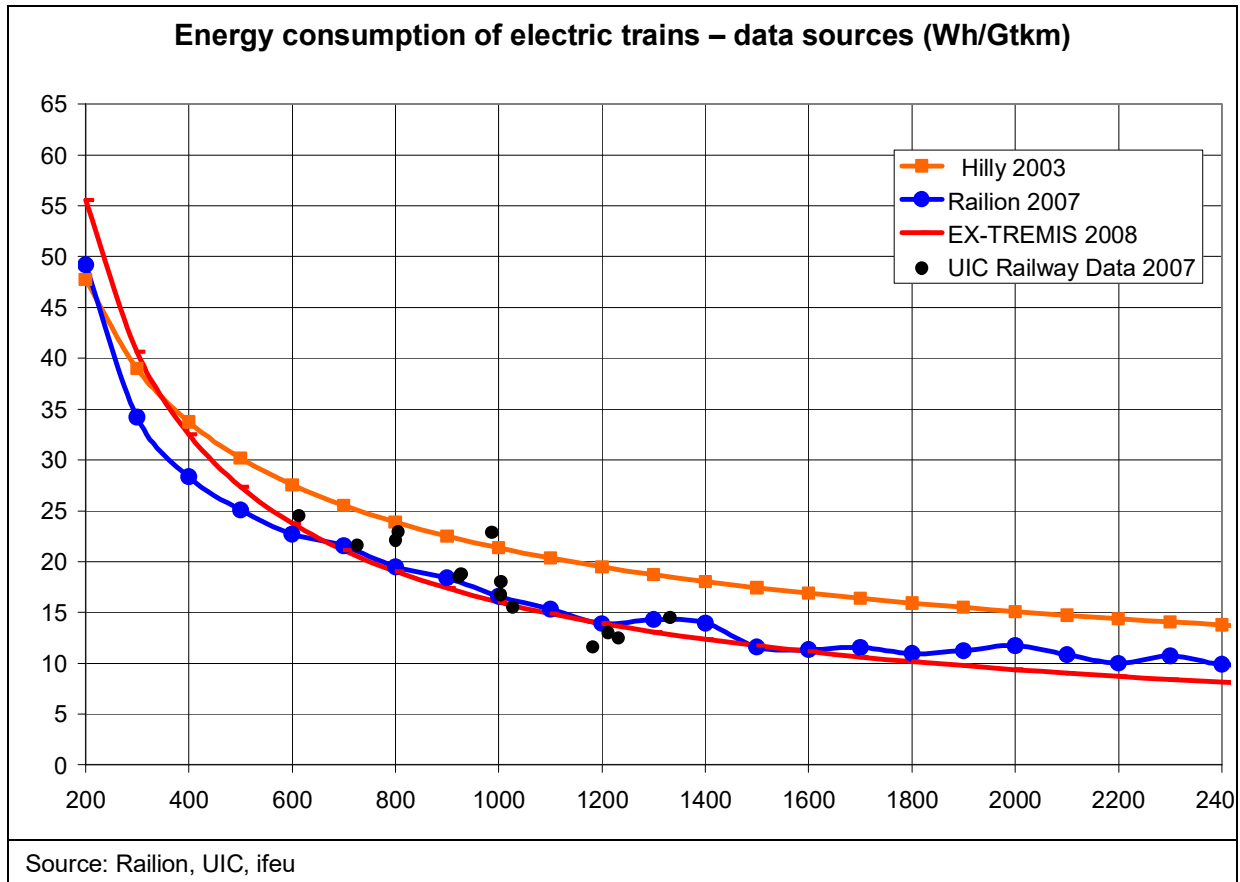
- Average annual consumption of typical freight transport by different companies, e.g. data from UIC energy statistics (last update 2007) /UIC 2009/.
- Analysis of energy consumption of more than 200,000 rides of freight trains by Railion in 2007 in different production types and train weight classes /Railion 2007/.
- Survey of train rides at the Gotthard line by SBB, mainly model calculations; values between 17 and 23 Wh/Gtkm /SBB 2006/.

- Canada: statistics about annual average energy consumption of freight trains. In 2003 the average energy consumption of diesel freight trains was recorded as 33 Wh/Gtkm and 61 Wh/Ntkm (average train weight in UIC-statistic 2007: about 5000 gross tonnes) /EPS 2005/.
- China: average energy consumption of extra-large double deck container and normal trains: Diesel 27 Wh/Gtkm, Electric 10 Wh/Gtkm (train weight about 4000 gross tonnes) /ifeu 2008/.
- US Track1: statistics about annual energy consumption of freight trains; in 2006 the average energy consumption of diesel freight trains was recorded as 66 kWh/Ntkm (average train weight in UIC-statistic 2007: about 5000 gross tonnes) /USDOT 2008/.
- The EX-TREMIS study, which is a kind of “official” dataset for Europe, proposed a function for rail freight transport, which is similar to EcoTransIT methodology /TRT 2008/.

The following diagram shows some of the values mentioned above, compared to the former function of EcoTransIT (hilly). The following conclusions can be stated:

- Nearly all values reside below the former EcoTransIT function.
- The function of EX-TREMIS stays very close to the Railion values in a range from 600 to 1800 gross tonnes.
- Some values from UIC statistics are higher than the Railion values, but the majority are in line with it.

Figure 14: Energy consumption of electric trains – data sources



ETW function includes the following assumptions:

- For train weights between 600 and 1800 gross tonnes, the Railion values correlate well with the function of EX-TREMIS and most of the UIC-values. Therefore, the following function correlated to these values was calculated:

$$EC_{\text{spec}} [\text{Wh/Gtkm}] = 1200 * \text{GTW}^{-0,62}$$

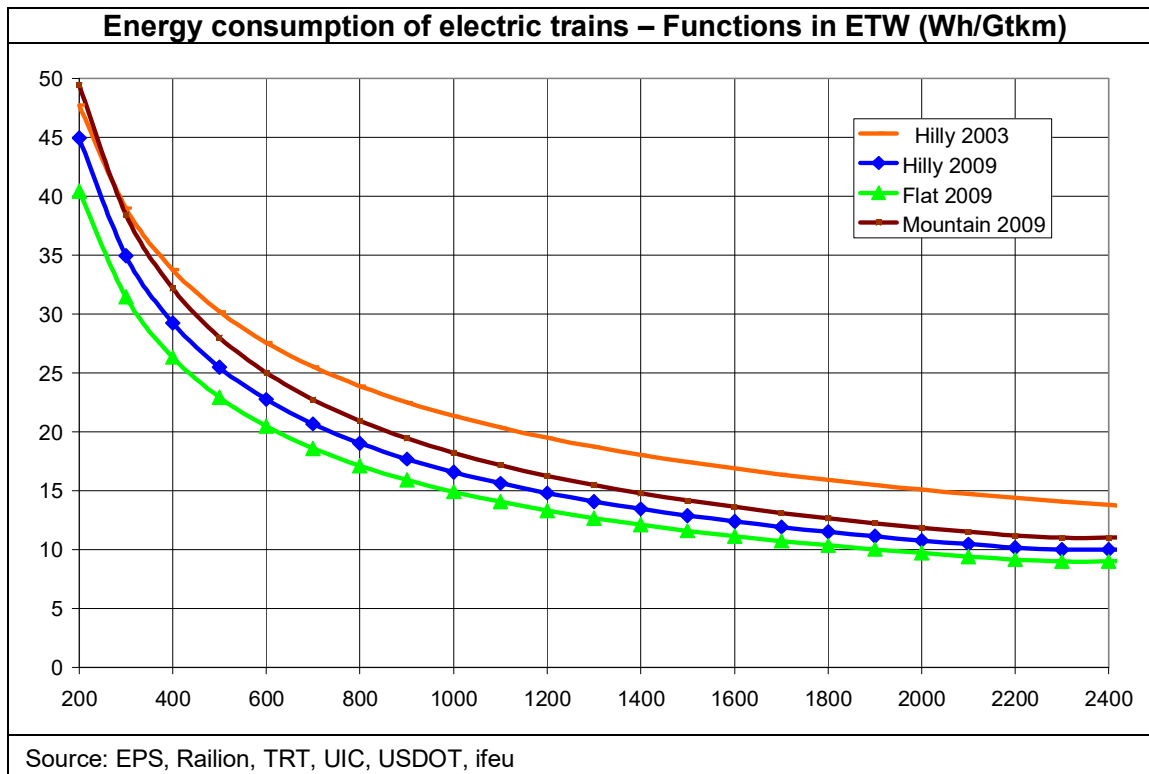
( $EC_{\text{spec}}$ : specific Energy Consumption, GTW: Gross Tonne Weight)

- Below 600 gross tonnes, the diffusion of the values is higher. This means a higher uncertainty of the values. We propose to use the same function as for the middle weight trains in order to define the function as simply as possible.
- Above 1500 gross tonnes, the Railion values show no significant reduction of specific energy consumption with growing train weight. This general trend is confirmed by values of heavy trains (4000 gross tonnes and more) for Canada, China and USA. Therefore, we propose to use the function until 2200 gross tonnes (specific energy value: 10 Wh/Gtkm) and keeping it constant for larger trains.

- The function is valid for “hilly” countries. For flat countries, the values of the function are multiplied by 0.9, for mountainous countries the factor is 1.1.

The following figure shows the resulting new functions compared to the EcoTransIT “Hilly 2003” function.

Figure 15 Functions for the energy consumption of electric trains



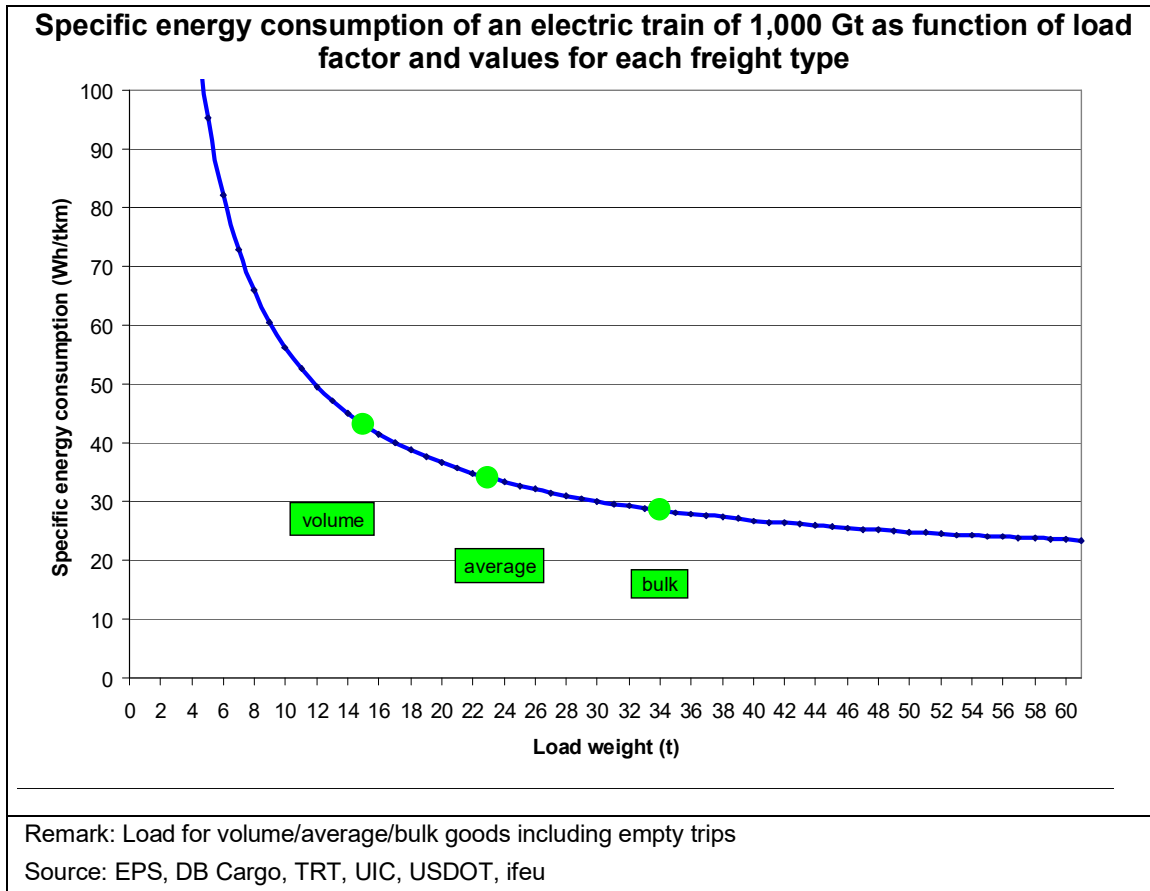
The specific energy consumption per net tonne km is calculated for each train type with the following formula:

$$\text{Specific energy consumption [Wh/Ntkm]} = \frac{\text{Energy consumption of train [Wh/Gtkm]}}{\text{Relation Nt/Gt of freight (including empty trip factor)}}$$

$$\text{Relation Nt/Gt} = \begin{cases} 0.40 & \text{for volume freight} \\ 0.52 & \text{for average freight} \\ 0.60 & \text{for bulk freight} \end{cases}$$

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 16 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

Train Type	Final Energy Consumption			
	Train	Bulk	Freight Average	Volume
	Unit	Wh/Gtkm	Wh/Ntkm	
<b>General trains</b>				
Light Train (500t)	25.5	42.7	49.5	63.9
Average Train (1000t)	16.6	27.8	32.2	41.5
Large (1500t)	12.9	21.6	25.0	32.3
Extra Large (2000t)	10.8	18.1	20.9	27.0
Heavy (>2000t)	10.0	16.8	19.4	25.1
<b>Dedicated trains</b>				
Car	20.7		69.3	
Chemistry	14.8		27.7	
Container	16.6		30.0	
Double Container	10.2		16.3	
Rolling Road - Truck	14.8		30.0	
Rolling Road - Semi Trailer	14.8		27.7	
Rolling Road - Swap Body	14.8		30,3	
Coal and steel	11.9		21.5	
Building materials	14.8		26.8	
Manufactured products	14.8		28.2	
Cereals	14.1		21.2	
Including vessel weight (container, truck, semi-trailer, swap body)				
Source: DB Cargo, SNCF, 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/. New 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

Train Type	Final Energy Consumption			
	Train	Freight		Volume
	Unit	Bulk	Average	
	Wh/Gtkm	Wh/Ntkm		
Light Train (500t)	68.8	115.5	133.7	172.6
Average Train (1000t)	44.8	75.2	87.0	112.3
Large (1500t)	34.8	58.4	67.6	87.3
Extra Large (2000t)	29.1	48.9	56.6	73.1
Heavy (>2000t)	27.0	45.4	52.5	67.8
<b>Values of heavy trains</b>	<b>Average (not specified)</b>			
China 2008	27			
Canada 2003	33			61
US Track 1 2006				66

Source: DB Cargo, ifeu 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 (NO<sub>x</sub>, NMHC, PM)

Standard	Manufacture year	HC	NO <sub>x</sub>	PM
International UIC (g/kWh)				
<b>UIC 1</b>	<b>&lt;=2002</b>	<b>0,8</b>	<b>12</b>	
<b>UIC 2</b>	<b>2003-2008</b>	<b>0,8</b>	<b>9,5</b>	<b>0,25</b>
European Union, P>560 kW (g/kWh)				
<b>Stage IIIa</b>	<b>2009-2011</b>	<b>0,5</b>	<b>6,0</b>	<b>0,2</b>
<b>Stage IIIb/V</b>	<b>&gt;=2012</b>	<b>0,2</b>	<b>3,8</b>	<b>0,025</b>
US-EPA, line-haul (g/bhp.hr)				
<b>Non regulated</b>	<b>&lt;1973</b>	<b>0,5</b>	<b>13,5</b>	<b>0,34</b>
<b>Tier 0</b>	<b>1973-1992</b>	<b>1,0</b>	<b>8,0</b>	<b>0,22</b>
<b>Tier 1</b>	<b>1993c-2004</b>	<b>0,6</b>	<b>7,4</b>	<b>0,22</b>
<b>Tier 2</b>	<b>2005-2011</b>	<b>0,3</b>	<b>5,5</b>	<b>0,10</b>
<b>Tier 3</b>	<b>2012-2014</b>	<b>0,3</b>	<b>5,5</b>	<b>0,10</b>
Tier 4	>2015	0,1	1,3	0,03
Source: <a href="http://www.dieselnet.com">www.dieselnet.com</a>				

### 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.

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

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

### 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	HC	NOx	PM
<b>Average values (g/kg), different sources</b>				
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 (MTU-shunting), which is described in [ifeu 2003].

The following assumptions are made for a shunting process:

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

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

## 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 CO<sub>2</sub> 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 **Fehler! Verweisquelle konnte nicht gefunden werden.**), 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:

- $W_{ME,Ship}$  = Propulsive power demand of the main engine in kW
- $W_{REF}$  = Rated average main engine power at MCR [kW] /IMO 2020, Table 81 in Annex N/
- $t, t_{REF}$  = Actual draught and design draught of the ship.  
Since no data on actual draught are available, the ratio of the two is currently assumed to equal 1 in ETW.
- $v, v_{REF}$  = Actual speed and design speed of the ship. This ratio is also set to 1 at 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.

$CF_{Weather}$  = Correction factor for the influence of weather (wind, waves). Based on Table 44 in /IMO 2020/.

$CF_{Fouling}$  = Correction factor for the influence of hull fouling/hull roughness. Based 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:

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

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:

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

With

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

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

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

$d_{port}$  = Number of days in port per year

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

$n$  = Number of auxiliary engines/boilers /IMO 2020/

$Dist$  = Annual distance driven by the 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/size class 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 actually 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 technology	S content in fuel	CO2 EF [g/g]	Energy content [MJ/kg]	Energy share in 2020	
					Inside ECA	Outside ECA
HFO (Heavy fuel oil; also called HSFO, HSHFO)	Scrubber	2.60%	3.1140	40.5	0.0%	29.0%
	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 fuel-based” pollutants/components covered by ETW include fuel/energy consumption, CO<sub>2</sub> and SO<sub>x</sub>. 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<sub>x</sub>, NMVOC and PM.

Average emission/energy consumption factors of fuel-based components (energy consumption, CO<sub>2</sub> and SO<sub>x</sub>) 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

$EF_{p,MT,area}$  = Emission / consumption factor in g/tkm for pollutant  $p$ , machine type  $MT$  (i.e. main engine/auxiliary engine/boiler) and area type  $a$  (inside/outside ECA)

$a$  = Area type (inside/outside ECA)

$FT$  = Fuel/technology type (see Table 35)

$OA$  = operation area (at sea or in port)

$AG$  = Age group: For specific fuel consumption (i.e. engine efficiency), the following age groups (“generations”) are differentiated:

- Engines built before 1983
- Engines built 1984-2000
- Engines built from 2001 onwards

$ET$  = Engine type (for diesel engines): SSD (Slow speed diesel), MSD (medium speed diesel), and HSD (high speed diesel).

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/.

$Sh_{FT,a}$  = Share of fuel/technology type  $FT$  in area type  $a$  (see Table 35)

$Sh_{AG}$  = 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 /FOEN 2015/)

$W_{MT,OA}$  = Power demand of machine type  $MT$  (i.e. main engine/auxiliary engine/boiler) in operation area  $OA$  (at sea/in port) in kWh/tkm

$SFC_{FT,AG,MT,ET}$  = Specific fuel consumption of engine type  $ET$ , machine type  $MT$  with fuel/technology type  $FT$  and in age group  $AG$ . See /IMO 2020/, Table 19

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

Sources:

- CO<sub>2</sub>, energy consumption: See Table 35
- SO<sub>x</sub>: 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 SO<sub>x</sub> emissions compared to HFO use without scrubber based on /Yang et al. 2017/.

For energy-based pollutants (NO<sub>x</sub>, NMVOC and PM), average emission factors are calculated using the following equation:

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

With

$AG$  = Age group: For PM, base emission factors are differentiated by the same “generations” as specific fuel consumption (see above).

For NO<sub>x</sub>, 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  $MT$  and, in the case of PM and NO<sub>x</sub>, age group  $AG$ .

Sources:

- NO<sub>x</sub>: 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 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-continental Europe	Transatlantic trade	Other global trade	Other global trade	Suez trade	Other global trade
NA - North Am.	Transatlantic trade	Intra-continental (non Europe)	Panama trade	Other global trade	Transpacific trade	Other global trade
LA - Latin Am.	Other global trade	Panama trade	Intracontinental (non Europe)	Other global trade	Other global trade	Other global trade
AF - Africa	Other global trade	Other global trade	Other global trade	Intracontinental (non Europe)	Other global trade	Other global trade
AS - Asia	Suez trade	Transpacific trade	Other global trade	Other global trade	Intracontinental (non Europe)	Other global trade
OZ - Oceania	Other global trade	Other global trade	Other global trade	Other global trade	Other global trade	Intracontinental (non Europe)

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

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
Great Lake BC		< 30,000 DWT

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

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.

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 than 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 carriers<sup>5</sup>. 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 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 vessels<sup>6</sup>. 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 dead-weight 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/.

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<sup>5</sup> 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](http://www.marinetraffic.com) were consulted.

<sup>6</sup> 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

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

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

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

$EF_M$  = Fuel consumption or emission factor of the main engine [g/tkm]

$LAF$  = Low-load adjustment factor for air pollutants: Inter-/extrapolated based on factors for given load points and pollutants in Table 20, /IMO 2020/

$EF_{A,Sea}$	= Fuel consumption or emission factor of the auxiliary engine at sea [g/tkm]
$EF_{B,Sea}$	= Fuel consumption or emission factor of the boiler at sea [g/tkm]
$EF_{A,Port}$	= Fuel consumption or emission factor of the auxiliary engine in port [g/tkm]
$EF_{B,Port}$	= Fuel consumption or emission factor of the boiler in port [g/tkm]

## 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

$EF_{final}$	= Cargo utilization-adjusted final fuel consumption or emission factor [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<sub>x</sub>, PM, or NO<sub>x</sub>, or all three pollutants, subject to a proposal from a Party to Annex VI. For NO<sub>x</sub>, the date of entry into effect applies only to ships constructed after that date, while for SO<sub>x</sub> and PM, all ships must comply from the date of entry into effect. This difference is due to the fact that SO<sub>x</sub> 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<sub>x</sub> emissions, a new or upgraded engine is required.

Existing Emission Control Areas include<sup>7</sup>:

- Baltic Sea (SO<sub>x</sub> in effect from 2006, NO<sub>x</sub> in effect from 2021)
- North Sea (SO<sub>x</sub>, in effect from 2007, NO<sub>x</sub> from 2021)
- North American ECA, including most of US and Canadian coast (SO<sub>x</sub>, and PM in effect from 2012, NO<sub>x</sub> from 2016).
- US Caribbean ECA, including Puerto Rico and the US Virgin Islands (SO<sub>x</sub>, and PM in effect from 2014, NO<sub>x</sub> from 2016).

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

Different options exist to comply with the emission limits in ECAs. Currently the most widespread is to use ULSFO (ultra-low sulphur fuel oil) or MDO/MGO, which has a sulphur content of 0.1% (compare Table 35). Other options are to use a scrubber, an after-treatment technology that uses sea water to wash SO<sub>2</sub> 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).

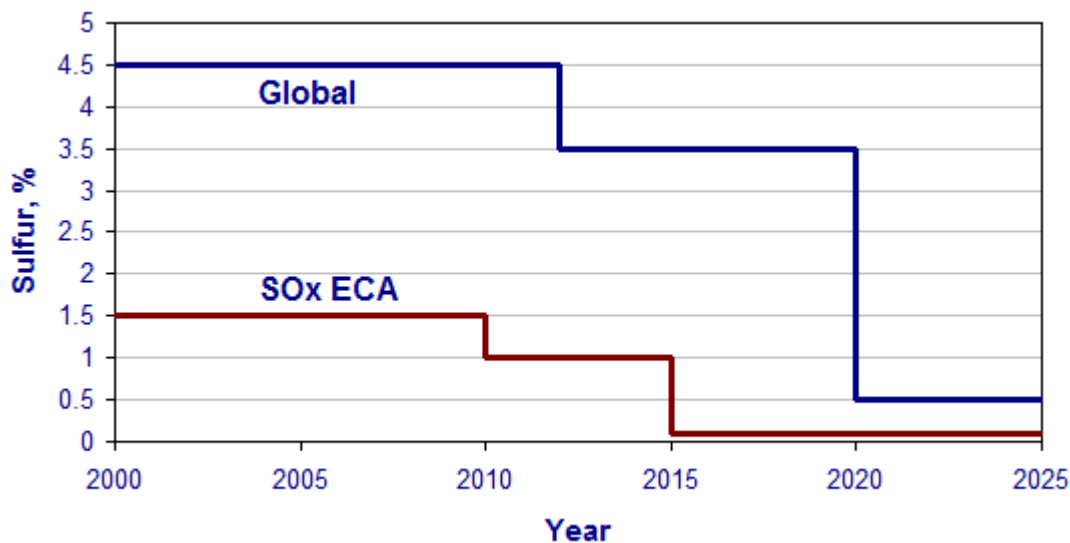
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<sup>7</sup> <https://www.imo.org/en/OurWork/Environment/Pages/Special-Areas-Marpol.aspx>

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 17 MARPOL Annex VI fuel sulphur limits (source: Dieselnets 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 TEU-km 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 **Fehler! Verweisquelle konnte nicht gefunden werden.**).

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

The fuel consumption per net tonne-kilometre (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 6.2):

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

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]

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

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

The same pollutant emission factors in g/g fuel have based on /IMO 2015/ are used as for other sea transport (see Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**), assuming a share of 65% of the main engine in total fuel consumption (based on /IMO 2015/).

## 6.4 Inland waterway transport

### 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-IV<sup>8</sup>;

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<sup>8</sup> Large navigable waterways are classified by the CEMT standard created by the European Conference of Ministers of Transport (**C**onférence **E**uropéenne des **M**inistres

- 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 tkm-weighted 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 CO<sub>2</sub> 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 Europe. All European waterways class IV and above are included in ETW (Figure 18). Most prominent are the rivers Danube, Elbe, Rhine, and Seine<sup>9</sup>, 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

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

<sup>9</sup> 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.

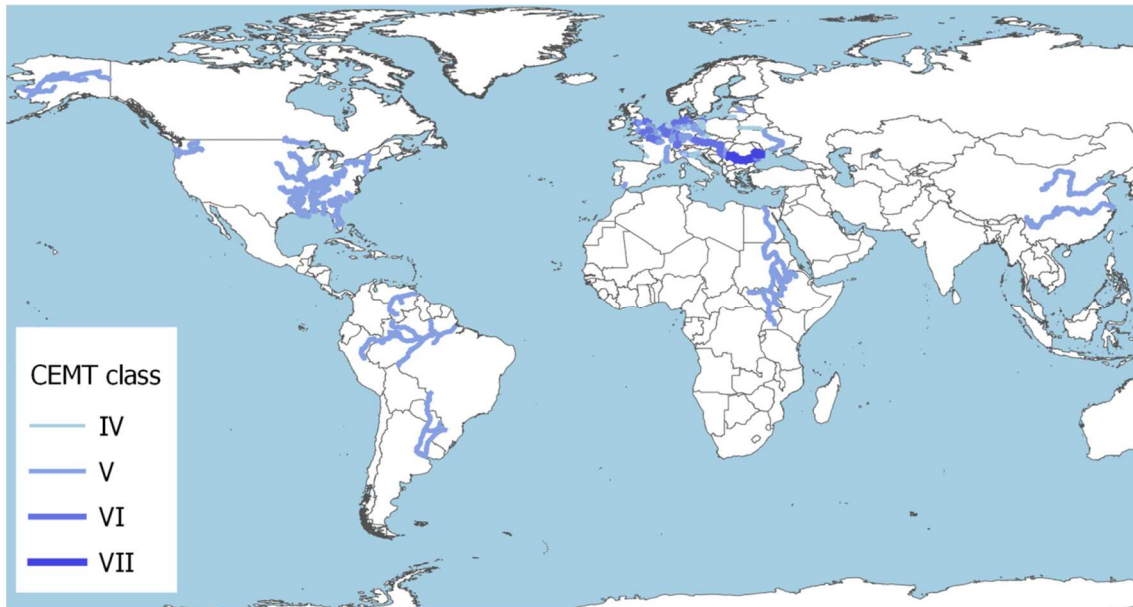
size and carrying capacity of inland barges significantly increases on class V and larger rivers.

Figure 18: 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 19).

Figure 19: Worldwide inland waterways in ETW.



### 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/

$LF_{CU}$  = Load factor at default cargo utilization /ifeu and INFRAS 2013/

$V$  = Speed [km/h] /ifeu and INFRAS 2013/

$CU$  = Default cargo utilization /ifeu and INFRAS 2013/

$Cap$  = Capacity (dead weight tonnage or TEU) /Panteia 2013/

$SFC$  = Specific diesel consumption in g/kWh (200 g/kWh for all 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/:

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

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

Vessel type	Default for CEMT river class	Length [m]	Beam [m]	Installed power [kW]	Average speed [km/h]	Capacity		Default cargo utilization	
						DWT (bulk)	TEU (Container)	Bulk	Container
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 stages and emission factors available for ETW. The factors have been derived from measurements and literature data for European ships in /ifeu and INFRAS 2013/. For the more recent stages US Tier 3 and US Tier 4, values have been derived from the emission limits and certification data by the EPA in 2014 and 2015 for category 1 and 2 engines /EPA 2015/.

Table 42 Inland vessel engine emission factors

Emission stage (manufacture year)	NOx (g/kWh)	NMHC (g/kWh)	PM (g/kWh)
conventional (1970-2002) / US Tier 1	11,67	0,52	0,32
CCNR I (2002-2006)	9,00	0,39	0,12
CCNR II/ EU IIIA / US Tier 2 (>2006)	7,00	0,29	0,12
US Tier 3	5,10	0,28	0,12
US Tier 4	1,4	0,06	0,03
Source: /ifeu and INFRAS 2013/, /EPA 2015/, dieselnet.com, ifeu assumptions			

According to evaluations in /ifeu and INFRAS 2013/ it was estimated that the average engine age for German and Dutch ships in 2011 was around 20 years. It can further be estimated that currently more than half of the transport performance in Germany is carried out by ships with no type approved engines (thus older than 2002). Also, most countries outside Europe or the US have no regulation for inland ship engines. Thus, the stage “conventional (1970-2002) / US Tier 1” is used as default value. For Germany, which may be representative for Western Europe, this will result in slightly higher emissions than for the average fleet. However, expert users can calculate emissions with newer emission stages 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

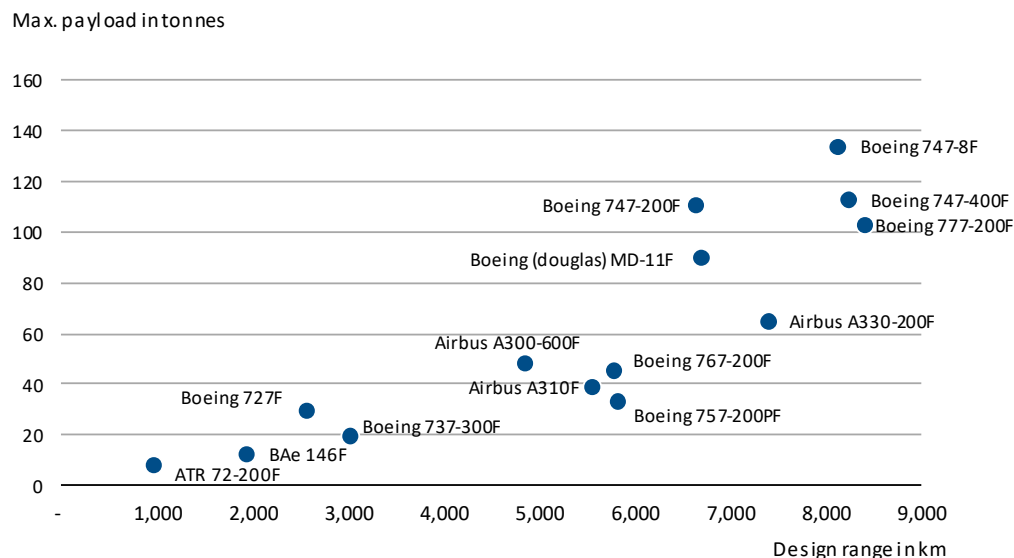
#### 6.5.1 Type of airplanes and load factor

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 7.4.

Each aircraft is characterised by both a maximum possible design range and a maximum payload (maximum freight weight). Large passenger aircrafts can fly without stopovers more than 10,000 km, whereas smaller ones have maximum ranges of 2,000 to 3,000 km /Lang 2009/. Aside from that, 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 **Fehler! Verweisquelle konnte nicht gefunden werden.** 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 20 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 **Fehler! Verweisquelle konnte nicht**

**gefunden werden.**) 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 62 in the annex. In the extended input mode of ETW, all aircraft types are available and may be chosen by the user.

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”. Worldwide between 40% and 48% of freight ton-kilometres in air cargo is transported by freighter /lower value Statista 2018; higher value ICAO 2018/. The lower value is used for the hybrid aircrafts of EcoTransIT independent of flight distance. 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 40% freighter and 60% belly freight. In the standard mode EcoTransIT shows only the mixed result of this hybrid aircraft.

Table 43 Characteristics of selected aircrafts

Type	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 NO<sub>x</sub>, 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 justifiable.

The basis of fuel consumption for the different airplanes considered by ETW is the EUROCONTROL “Small Emitters Tool”<sup>10</sup> which has been developed on behalf of the European Commission for reporting under the European Emissions Trading Scheme (ETS) /EUROCONTROL 2009,2015, 2017 and 2019/. 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 (e.g. 2017). 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 21) /EUROCONTROL 2009/. In total measured energy consumptions are available for around 85 different aircraft types in the Small Emitters Tool.

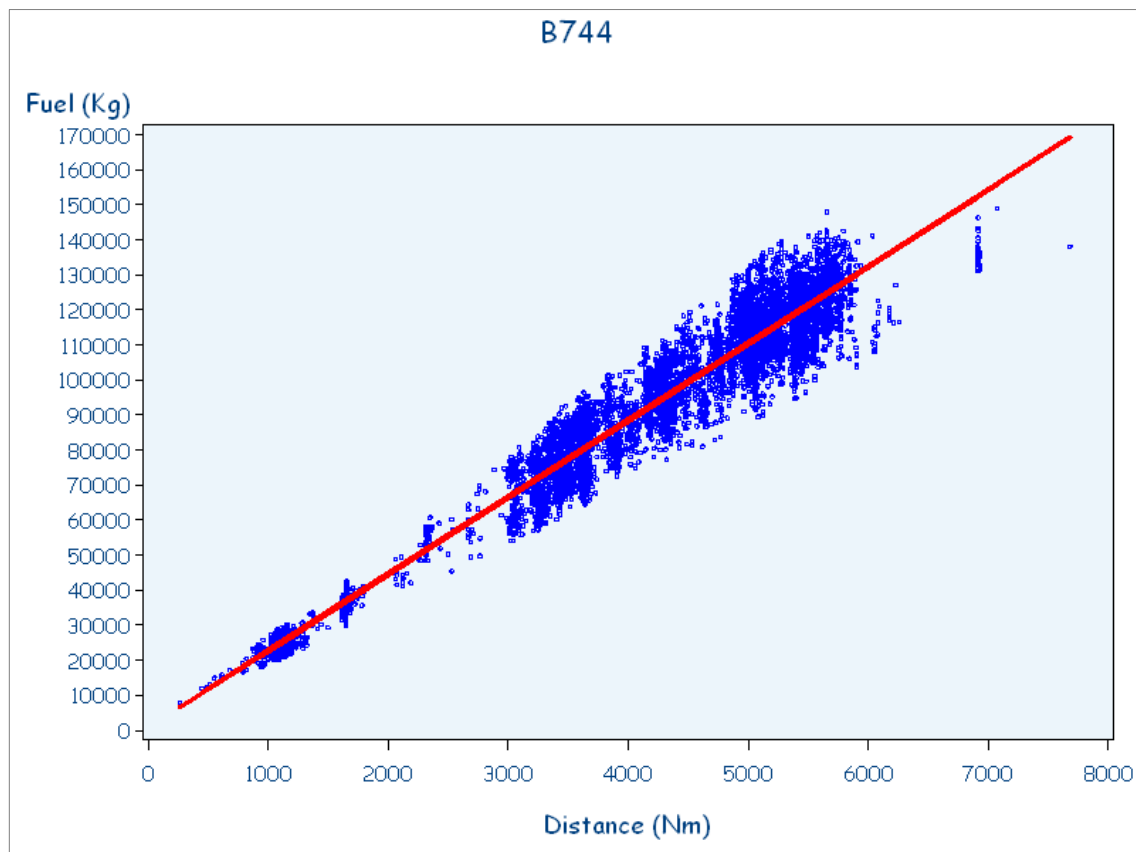
In a second step the Small Emitters Tool uses conclusions by analogy for aircraft families. That means that for aircrafts without measured fuel-burn data the energy consumption of other aircraft types of the same family is used (e.g. fuel-burn data from B747-400 for B747-300). In these cases, the measured data are adjusted by using a

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

correction factor based on the MTOW (maximum take-off weight) ratio /EUROCONTROL 2009/. This approach is used for around 30 airplanes. In a third step data from the EMEP/EEA Air 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 270) 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/.

Figure 21 TTW energy consumption of the Small Emitters Tool is based on a linear regression of fuel-burn data collected in Europe – example of a Boeing 747-400 /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 32 freighter and passenger aircrafts considered in ETW are based on measured fuel-burn data collected in context of the Small Emitters Tool. Only for three aircrafts conclusions by analogy from other family models are used (Boeing 777-200/200ER, Boeing 777F and Boeing (McDonnell Douglas) MD-90). For four further aircraft types the method of linear regression based on all available data is applied (Boeing 727F, Boeing 747-8F,

Boeing 747-8i and Boeing 787-8). 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

Distance (km)	Dedicated freighter			Passenger aircrafts		
	Boeing 737-300SF (kg)	Boeing 767-200F (kg)	Boeing 747-400F (kg)	Embraer 190 (kg)	Airbus 320 (kg)	Boeing 747-400 (kg)
232	1,570	2,119	5,744	1,366	1,527	5,744
463	2,285	3,383	8,381	1,912	2,217	8,381
926	3,714	5,911	13,655	3,004	3,597	13,655
1,389	5,143	8,439	18,928	4,096	4,977	18,928
1,852	6,572	10,967	24,202	5,188	6,357	24,202
2,778	9,431	16,023	34,749	7,371	9,118	34,749
3,704	12,289	21,079	45,296	9,555	11,878	45,296
4,630		26,135	55,843		14,638	55,843
5,556		31,191	66,389		17,399	66,389
6,482		36,248	76,936		20,159	76,936
7,408			87,483			87,483
8,334			98,030			98,030
9,260						108,577
10,186						119,124
11,112						129,671
12,038						140,218
12,964						150,765
13,890						161,312

Source: EUROCONTROL Small Emitters Tool /EUROCONTROL 2017/

CO<sub>2</sub>, CO<sub>2</sub> equivalents and SO<sub>x</sub> depend directly on the amount of kerosene consumed by the airplanes. For CO<sub>2</sub>-equivalent the emission factors of the European standard EN 16258 are used without changes (see Table 45 and Table 57). The CO<sub>2</sub> emission factor used by ETW is based on the same sources than the CO<sub>2</sub> equivalent emission factor included in the European standard so that the CO<sub>2</sub> emissions calculation of ETW is comparable with the approach of EN 16258. For SO<sub>x</sub> 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 SO<sub>2</sub> per kg kerosene in 1998 and 0.2 g SO<sub>2</sub> per kg kerosene in 2009 is used /Öko-Institut 2010; ifeu and Öko-Institut 2012/.

Table 45: Fuel-based emission factors for CO<sub>2</sub>, CO<sub>2e</sub> and SO<sub>x</sub> (TTW) for kerosene (jet A and jet A1)

	<b>g/kg fuel</b>
Carbon dioxide (CO <sub>2</sub> )	3.15
Carbon dioxide equivalents (CO <sub>2e</sub> )	3.18
Sulphur dioxide emissions (SO <sub>x</sub> )	0.84
Sources: EEA 2013/2015; EN DIN 2012; Öko-Institut 2010.	

NO<sub>x</sub>, 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<sub>x</sub>, 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 NO<sub>x</sub>, 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.

Table 46 NO<sub>x</sub>, HMHC and PM emissions of aircraft type Boeing 747-400 (freighter)

Distance (km)	NO <sub>x</sub> (kg)	NMHC (kg)	PM (kg)
232	126	2.8	0.6
463	171	3.1	0.9
926	227	3.7	1.5
1,389	290	4.2	2.1
1,852	353	4.6	2.6
2,778	472	5.8	4.2
3,704	607	6.5	5.0
4,630	734	7.4	6.2
5,556	863	8.3	7.4
6,482	988	9.1	8.6
7,408	1.126	10.3	9.8
8,334	1.248	11.2	11.0
9,260	1.373	12.1	12.1
1,186	1.506	13.0	13.3
1,112	1.783	15.0	15.9
12,038	2.239	17.9	19.9
12,964	2.509	19.9	22.5
13,890	2.930	22.8	26.4
Sources: EEA 2013/2015; INFRAS calculations.			

### 6.5.3 Emission Weighting Factor (EWF)

Some air pollutants (in particular nitrogen oxides, ozone, water, soot, sulphur) emitted by aircrafts in cruising altitude can have an additional climate impact to CO<sub>2</sub> /IPCC 1999/. To express these additional climate impact very often the so called “Radiative Forcing Index” (RFI) is used. For cruise in critical altitudes over 9 kilometres the RFI factor lies between 2 and 4 (on average 3). That means that the total climate impact of the emissions of airplanes is twice or four times higher compared to the TTW CO<sub>2</sub> emissions /UBA 2008; IPCC 2006/.

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 CO<sub>2</sub> 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 CO<sub>2</sub> over a time period of 100 years /Graßl and Brockhagen 2007/.

EFW is also applied for cruising in an altitude over 9 kilometres and lies between 1.2 and 2.7. For ETW the user can choose to consider the EWF for the calculation of the CO<sub>2</sub> equivalent emissions. In this case an average EWF of 2.4 for flights over 9 kilometres is used based on ifeu/Öko-Institut /2012/<sup>11</sup>. These altitudes are usually reached in the cruise phase of flights with distances greater than approx. 400–500 km /Atmosfair 2007/. Therefore, in ETW the use of the EWF is only included as an option for flights with distances over 500 km. The average EWF for the entire flight including take-off and landing is listed in Table 47 according to the total flight distance.

In this context it has to be pointed out that considering EWF (or RFI) for the calculation of CO<sub>2</sub> 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 CO<sub>2</sub> 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.

Table 47 Average Emission Weighting Factor (EWF) depending on flight distance

Flight Distance [km]	Average EWF
500	1
750	2
>1,000	$\frac{300 + (Distance [km] - 300) * 3}{Distance [km]}$
Sources: Graßl/Brockhagen 2007; Atmosfair 2009; ifeu/Öko-Institut 2012; INFRAS calculations.	

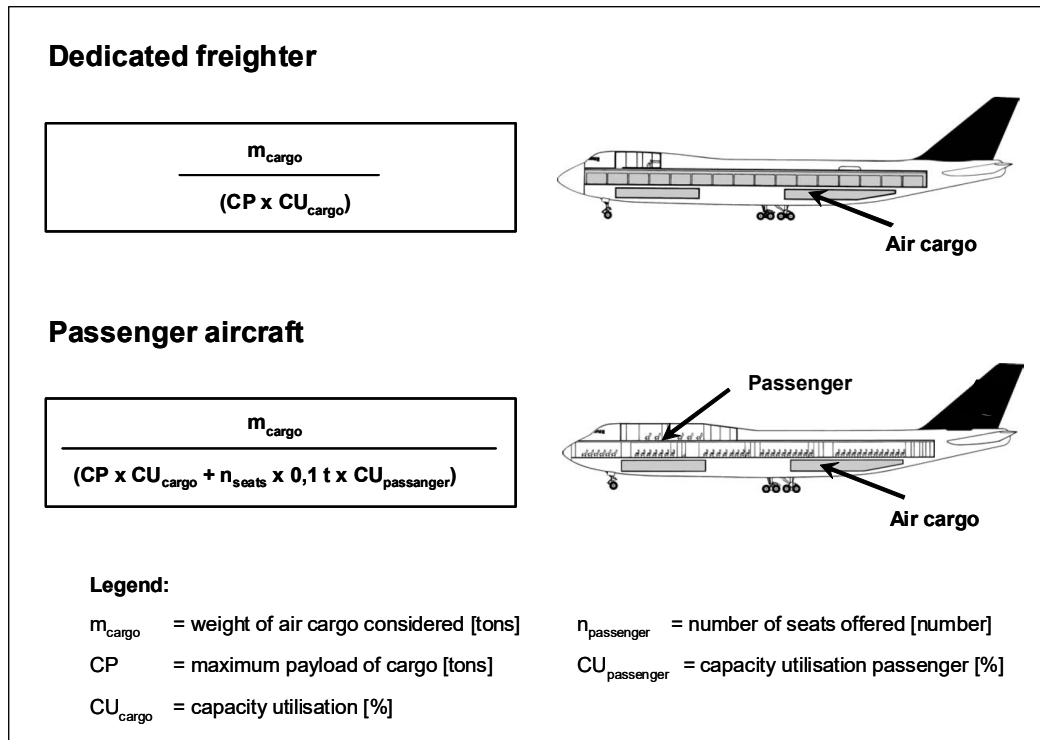
#### 6.5.4 Allocation method for belly freight

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

<sup>11</sup> In this case the TTW CO<sub>2</sub> equivalent emissions are calculated by multiplication of the TTW CO<sub>2</sub> emissions with the factor 2.4

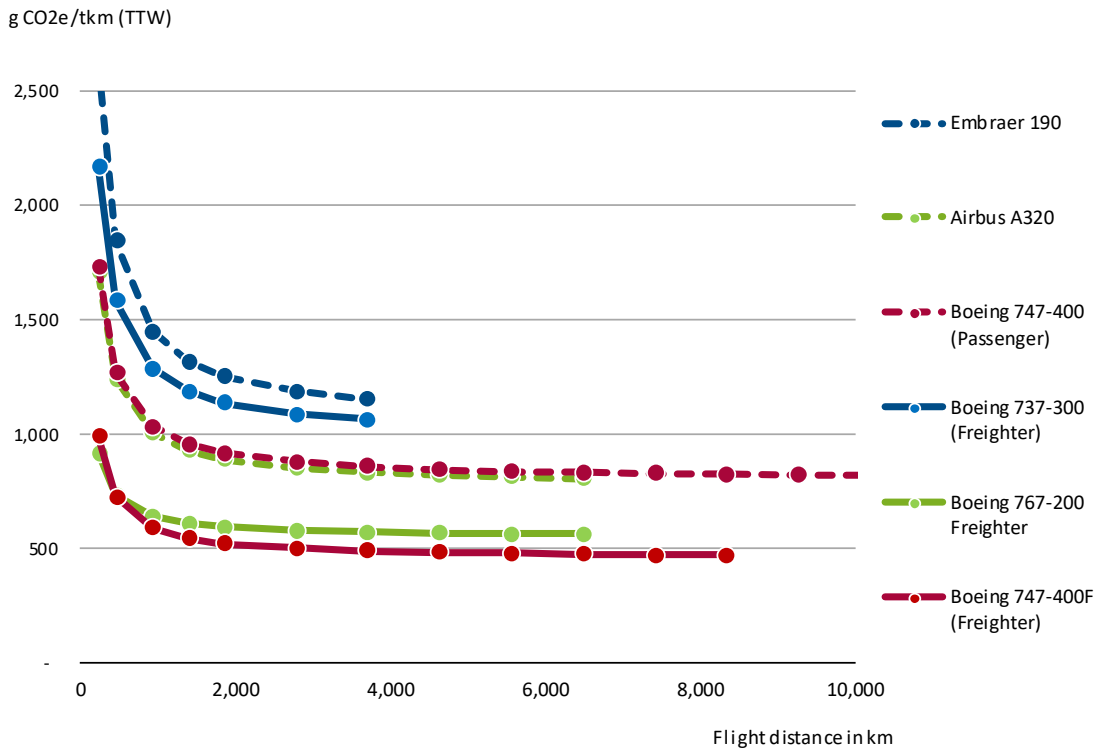
2012/. ETW uses the approach used (and required) by the European Standard EN 16258. In accordance with EN 16258 a weight of 100 kg (= 0.1 t) per passenger is assumed. Figure 22 contains the concrete formula to allocate the energy consumption and emissions of passenger aircrafts.

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 CO<sub>2</sub> emissions of belly cargo is 20 to 80% higher as air cargo transported by dedicated freighters. Additionally, the figure shows that the specific CO<sub>2</sub> 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.

Figure 23 Specific TTW CO<sub>2</sub> emissions of selected freighter and passenger aircrafts in g/tkm used for the ETW standard input mode /EUROCONTROL 2017; INFRAS calculations/



## 6.6 Energy consumption and emissions of the upstream process (WTT)

Additional to the emissions caused directly by operating the vehicles (Tank-to-Wheels/TTW) emissions and energy consumption of the **generation of final energy (fuels, electricity)** are taken into account by ETW (Well-to-Tank/WTT). The impacts of extraction and generation of the different energy carrier are also included. Considering Tank-to-Wheels energy consumption and GHG emissions as well as Well-to-Wheels energy consumption and GHG emissions (sum of TTW and WTT) is a requirement of the European standard EN 16258. ETW provides TTW as well as WTW 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 EN 16258.

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
- In the case of natural gas compression (CNG) or cooling and liquefaction (LNG)
- Energy distribution (transport to service station, filling losses)

For every process step, energy is required. Most of the energy demand is covered with fossil primary energy carriers. But renewable energy carriers and nuclear power are also applied. The latter is associated with low emissions, but may also have environmental impacts on human health and ecosystems.

#### **6.6.1 Exploration, extraction, transport and production of fossil fuels**

The greenhouse gas emission factors and the energy demand for refineries, exploration and preparation of different input fuels, the transport to the refineries, the conversion in the refinery and transport to the filling station are taken from EN 16258 (see Table 57 in the annex). The other emission factors are from two different data sources: [ifeu / INFRAS / LBST 2015] and the ecoinvent database (version 3.2 using the cut-off approach) [ecoinvent 2013]. For each fuel supply chain, the data source that best represented the EN 16258 values concerning fuel properties (lower heating value), greenhouse gas emissions and energy demand was chosen.

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

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

Fuel	NOx kg/TJ	SO <sub>2</sub> kg/TJ	NMHC kg/TJ	PM kg/TJ
Gasoline	36.3	27.8	53.0	1.4
Diesel, MDO, MGO	38.4	30.9	24.9	1.5
Kerosene	38.4	30.9	24.9	1.5
Heavy fuel oil	38.8	87.1	32.4	7.0
CNG	28.1	3.9	0.9	0.8
LNG	21.9	42.6	6.0	3.1

Source: heavy fuel oil [ecoinvent 2013] all others [ifeu / INFRAS / LBST 2015]  
Assumptions: CNG average pipeline transport distance 4000 km; LNG imported by ship from Katar to the EU

## 6.6.2 Production of biofuels

Previously, biodiesel and ethanol emission factors were taken from the EN 16258. However, this norm is fairly old, and its 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 CO<sub>2</sub> (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 JEC (2020), but supplemented by the non-GHG emissions.

Table 49 summarises the non-GHG emission factors for the biofuels. The GHG emission factors can be found in appendix 7.

Table 49 Emission factors for energy production of biofuels (WTT)

Fuel	NOx mg/MJ	SO <sub>2</sub> mg/MJ	NMHC mg/MJ	PM mg/MJ
Biodiesel	71.95	32.93	4.96	4.75
Ethanol	95.56	25.02	7.13	5.08
Bio CNG	44.57	17.34	3.54	4.52
HVO/ HEFA*	51.13	13.09	4.34	3.47
Bio LNG	43.40	22.58	4.07	5.80

Source: ifeu calculations

\* HVO/ HEFA can also be used as a marine fuel or a sustainable aviation fuel

Further information on carbon dioxide and other greenhouse gas emissions as well as energy use from biofuels can be found in annex 7.

### 6.6.3 Electricity production

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.

The preferred method to estimate emission factors for electricity production on a general (not company specific) level is to use the average electricity split per year and country. This approach is recommended by the European standard EN 16258.

Single companies often buy electricity on the marked (e.g. green electricity) with different energy mixes and therefore different emission factors. The EN 16258 allows the use of such values on a company level. 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. This also violates the rules of EN 16258.

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 recommendations of EN 16258. 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 basic 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 50) stems from EUROSTAT and the International Energy Agency (IEA) and the reference year is 2019.

Table 50 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.*

**Fehler! Ungültiger Eigenverweis auf Textmarke.** shows the emission values at pantograph for the different countries/ regions.

Table 51 Energy and emission factors of the electricity supply for railway transport (WTT at pantograph) in 2019

Region	Energy factor (MJ/ MJ)	CO <sub>2e</sub> (g/ MJ)	CO <sub>2, fossil</sub> (g/ MJ)	NO <sub>x</sub> (g/MJ)	SO <sub>2</sub> (g/ MJ)	NMHC (g/ MJ)	PM10 (g/ MJ)
Africa	3.11	244	233	0.528	0.640	0.034	0.046
Asia (excluding China)	2.84	267	258	0.649	0.691	0.035	0.045
Austria	1.31	49	44	0.057	0.031	0.011	0.002
Australia	2.90	264	255	0.425	0.460	0.037	0.037
Bosnia	2.76	270	266	0.208	1.066	0.007	0.061
Belgium	2.86	52	49	0.054	0.019	0.012	0.002
Bulgaria	3.45	172	168	0.165	0.637	0.009	0.039
Brazil	1.43	40	36	0.079	0.064	0.012	0.005
Canada	2.00	50	47	0.057	0.067	0.011	0.004
Switzerland	2.35	3	2	0.010	0.004	0.003	0.001
Chile	2.05	159	150	0.468	0.185	0.033	0.016
China (including Hong Kong)	2.30	228	221	0.752	0.623	0.024	0.043
Cyprus	3.40	252	244	0.282	1.179	0.122	0.058
Czech Republic	3.42	193	184	0.190	0.504	0.011	0.032
Germany	2.21	132	123	0.123	0.094	0.013	0.007
Denmark	1.21	50	44	0.153	0.040	0.008	0.007
Estonia	2.36	250	238	0.306	0.956	0.012	0.056
Greece	2.45	182	177	0.157	0.427	0.041	0.023
Spain	2.32	75	72	0.105	0.109	0.020	0.008
EU28	2.52	96	90	0.147	0.172	0.018	0.014
Finland	2.30	51	46	0.137	0.049	0.008	0.006
France	3.69	20	18	0.032	0.018	0.006	0.003
FSU 15	3.23	188	174	0.289	0.257	0.047	0.028
Hong Kong	2.78	301	289	0.876	0.728	0.048	0.049
Croatia	1.76	83	74	0.183	0.116	0.014	0.018
Hungary	3.34	97	91	0.120	0.172	0.018	0.011
Ireland	1.75	100	97	0.108	0.043	0.012	0.003
Israel	2.73	221	211	0.433	0.340	0.021	0.041
India	2.79	292	285	0.846	1.087	0.028	0.071
Iran	2.95	197	190	0.181	0.157	0.028	0.009
Italy	2.06	116	106	0.150	0.097	0.035	0.007
Japan	2.42	180	169	0.346	0.206	0.041	0.018
South Korea	3.07	189	179	0.479	0.431	0.033	0.044
Lithuania	1.48	48	40	0.115	0.046	0.013	0.008
Luxembourg	1.23	46	36	0.132	0.025	0.013	0.005
Latvia	1.57	83	70	0.133	0.061	0.032	0.006
Montenegro	2.12	168	166	0.129	0.663	0.004	0.038

Middle East	3.37	240	225	0.240	0.432	0.101	0.017
Malta	1.92	146	139	0.121	0.084	0.040	0.002
Mexico	2.67	168	158	0.228	0.367	0.059	0.020
Netherlands	1.80	128	122	0.125	0.062	0.024	0.006
Norway	1.13	4	3	0.003	0.003	0.002	0.000
Non-OECD America	1.81	74	69	0.112	0.152	0.028	0.008
Non-OECD Europe and Eurasia	3.36	198	181	0.267	0.429	0.042	0.029
Poland	2.77	279	255	0.532	0.699	0.018	0.059
Portugal	1.68	91	86	0.167	0.135	0.025	0.010
Romania	2.72	138	134	0.118	0.435	0.016	0.025
Serbia	2.79	285	280	0.218	1.092	0.008	0.063
Russian Federation	3.29	188	175	0.258	0.268	0.048	0.024
Sweden	2.34	6	5	0.041	0.008	0.002	0.002
Slovenia	2.92	99	97	0.086	0.272	0.004	0.017
Slovakia	3.36	63	58	0.103	0.124	0.012	0.011
Turkey	2.31	167	159	0.159	0.143	0.020	0.009
United Kingdom	2.07	75	68	0.107	0.037	0.021	0.004
United States	2.77	152	144	0.195	0.195	0.028	0.012
World	2.70	190	180	0.413	0.378	0.028	0.036
South Africa	3.97	379	373	1.338	0.967	0.049	0.154

## 6.7 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 FAME<sup>12</sup> and 30% for hydro treated vegetable oil (HVO<sup>13</sup>). 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

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<sup>12</sup> Fatty Acid Methyl Ester

<sup>13</sup> Hydrotreated Vegetable Oils

EU 28 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 % =  $\text{biodiesel}/(\text{diesel}+\text{biodiesel})$  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 52 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 52: 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, their 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 53.

Table 53: Share of bio methane in road transport

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%

## 6.8 Cooled transports

Most refrigerated transports today call for an active cooling of the freight during transportation. To achieve this, often an additional energy demand results. 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 CO<sub>2</sub> 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 54 and are included into ETW.

Table 54 Overview on refrigerated transport modes in ETW

<b>Articulated Truck (60 t)</b>	<b>Rigid Truck (<math>\leq 40t</math>)</b>	<b>Train</b>	<b>Ship (not yet included in ETW)</b>	<b>Aircraft (not included in ETW)</b>
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 on-board 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 55.

Table 55: Specifications of the reefer (40' high-cube container)

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.

Table 56: Energy demand and emissions from diesel generator sets with 18 kW per kWh [ifeu, 2015]

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

\* Diesel demand taken from ThermoKing

For rigid trucks ( $\leq 40t$ ) 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 airfreight-cooling 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.

## 7 Appendix

### 7.1 Default conversion factors

Table 57 EN 16258 default values for fossil fuels and gases (energy and CO<sub>2</sub>e)

Fuel type description	density (d) kg/l	Energy factor MJ/kg		CO <sub>2</sub> e-factor kgCO <sub>2</sub> e/kg	
		TTW	WTW	TTW	WTW
	Gasoline	0.745	43.2	50.5	3.25
Diesel	0.832	43.1	51.3	3.21	3.9
Liquefied Petroleum Gas (LPG)	0.550	46.0	51.5	3.10	3.46
Compressed Natural Gas (CNG)	x	45.1	50.5	2.68	3.07
Aviation Gasoline (AvGas)	0.800	44.3	51.8	3.13	3.76
Jet Gasoline (Jet B)	0.800	44.3	51.8	3.13	3.76
Jet Kerosene (Jet A1 and Jet A)	0.800	44.1	52.5	3.18	3.88
Heavy Fuel Oil (HFO)	0.970	40.5	44.1	3.15	3.41
Marine Diesel Oil (MDO)	0.900	43.0	51.2	3.24	3.92
Marine Gas Oil (MGO)	0.890	43.0	51.2	3.24	3.92
Liquefied natural gas (LNG)* - not EN 16258	x	45.1	56.2	2.68	3.62

\* The EN 16258 does not contain default values for liquefied natural gas (LNG). For EcoTransIT, similar TTW values as for CNG are assumed (both fuels contain mainly methane). The WTT values base on ifeu / INFRAS / LBST 2015. The values are higher than for CNG due to higher energy intensity, especially for liquefaction.

Table 58 Default values for biogenic fuels and gases (energy and CO<sub>2</sub>e)

Fuel type description	density (d) kg/l	Energy factor MJ/kg		CO <sub>2</sub> e-factor gCO <sub>2</sub> e/MJ	
		TTW	WTW	TTW	WTW
	Biodiesel	0.892	37.0	85.4	0
Ethanol	0.780	27.0	76.9	0	47.9
HVO/ HEFA	0.770	44.0	79.0	0	28.6
Bio CNG	x	50.0	104.6	0	26.6
Bio LNG	x	50.0	110.6	0	31.2

Table 59 EN 16258 default values for fossil fuels and gases (CO<sub>2</sub>)


Fuel type description	CO <sub>2</sub> -factor kgCO <sub>2</sub> /kg	
	TTW	WTW
Gasoline	3.17	3.78
Diesel	3.16	3.84
Liquefied Petroleum Gas (LPG)	3.02	3.37
Compressed Natural Gas (CNG)	2.54	2.78
Aviation Gasoline (AvGas)	3.10	3.74
Jet Gasoline (Jet B)	3.10	3.74

Jet Kerosene (Jet A1 and Jet A)	3.15	3.85
Heavy Fuel Oil (HFO)	3.11	3.38
Marine Diesel Oil (MDO)	3.21	3.89
Marine Gas Oil (MGO)	3.21	3.89
Liquefied natural gas (LNG) - <b>not EN 16258</b>	2.54	3.21

Table 60 Default values for biogenic fuels and gases (CO<sub>2</sub>)

Fuel type description	CO <sub>2</sub> -factor gCO <sub>2</sub> /MJ	
	TTW	WTW
Biodiesel	0	24.0
Ethanol	0	34.8
HVO/ HEFA	0	19.2
Bio CNG	0	15.1
Bio LNG	0	19.3


# 7.2 Example for an ETW declaration in accordance with EN 16258



**EcoTransIT World**  
 EcoTransIT World (Ecological Transport Information Tool) berechnet die Umwandlungsfaktoren für verschiedene Transportarten in Güterverkehr. Dabei wird EcoTransIT den Energieverbrauch und die Treibhausgasemissionen von Transporten mit Bahn, LKW, Schiff und Flugzeug in Übereinstimmung mit den europäischen Normen EN 16258:2012 fest. Ergänzend werden die Kohlendioxidemissionen (CO<sub>2</sub>) und die wichtigsten Luftschadstoffemissionen (SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>10</sub> und PM<sub>2.5</sub>) für die wichtigsten Landtransportarten (LKW, Schiff und Flugzeug) für die Transportdienstleistungen ermittelt und dargestellt. Im Folgenden finden sie alle Angaben zu den von Ihnen in EcoTransIT ausgewählten Transportdienstleistungen sowie die resultierenden Energieverbräuche und Emissionen.

**General information**  
 Creation Date: 21.11.2014  
 Origin: (City: 49143)Hilfshaus  
 Destination: (City: 49143)Hilfshaus  
 Cargo weight: 100 kg (TGT: 10)

**Detailed description of the calculated transport services**  
**Transport service TS 1 - 495,29 km**  
 Origin: (City: 49143)Hilfshaus  
 Truck: Truck 04-49 (LKW) LKW 40,00 (LKW) 495,29 km  
 Destination: (City: 49143)Hilfshaus  
**Transport service TS 2 - 602,35 km**  
 Origin: (City: 49143)Hilfshaus  
 Truck: Truck 04-49 (LKW) LKW 40,00 (LKW) 602,35 km  
 Destination: (City: 49143)Hilfshaus  
**Transport service TS 3 - 602,35 km**  
 Origin: (City: 49143)Hilfshaus  
 Sea: Sea ship 02-Caspar (40-wei) 02CALP (80% Speed advance) 79% / 602,35 km  
 Destination: (City: 49143)Hilfshaus



**Energy consumption and green house gases (GHG) according to the EN 16258**

**Energy consumption**

Mode	Energy consumption (kWh/100kg)	CO <sub>2</sub> (kg/100kg)
Truck	18,1	19,9
Sea ship	1,2	1,3
<b>Total</b>	<b>19,3</b>	<b>21,2</b>

**CO<sub>2</sub> Equivalents**

Mode	CO <sub>2</sub> (kg/100kg)
Truck	19,9
Sea ship	1,3
<b>Total</b>	<b>21,2</b>

Diese vier Ergebnisse pro Transportdienstleistung (TTW- und WTW-Energieverbrauch und TTW- und WTW-Treibhausgasemissionen) wurden in Übereinstimmung mit der Norm EN 16258:2012 ermittelt. Um weitere Informationen über unterrichtliche Prozesse, Leitlinien und allgemeine Grundregeln zu erhalten, ist diese Norm herunterzuladen. Wenn Sie diese Ergebnisse mit anderen Ergebnissen vergleichen wollen, die nach dieser Norm berechnet wurden, sind insbesondere die unten angegebenen Verfahren zu beachten. Insbesondere die Abkürzungen sind zu beachten.

Die Norm EN 16258 enthält die folgenden Angaben zum Verfahren für die Berechnung von Energieverbrauch und Treibhausgasemissionen (THG-Emissionen) und oben in der Beschreibung der Transportdienstleistungen aufgeführt. Die von EcoTransIT für die Berechnungen verwendeten Energie- und THG-Umwandlungsfaktoren (z.B. MJ oder kg CO<sub>2</sub>-Äquivalente pro Liter Diesel) wurden umgerechnet vom Anfang bis der Norm EN 16258 übernommen. Beim LKW-Verkehr wird in Europa bezogen auf den Energieinhalt ein Basiswertfaktor im Diesel von fünf Prozent berücksichtigt. Für Bismarck enthält die Norm keine entsprechenden Energie- und THG-Umwandlungsfaktoren. EcoTransIT nutzt daher eigene, landesspezifische Umrechnungsfaktoren, die im wissenschaftlichen Grundlagensbericht dokumentiert sind (<http://www.ecotransit.org/basis-en.html>).

Bei der Allokation von Energieverbrauch und Treibhausgasemissionen (THG-Emissionen) auf die einzelnen Transportdienstleistungen wird die Kerngröße Tonnenkilometer (TKM) verwendet. Die Norm lässt über fünf Ausprägungen zu, wie dies bei den Verkehrsmitteln über 10. Daher wurden für Containerschiffe (TEU) sowie Fähren (Anzahl Decks und Fahrgastplätze) gemittelte Allokationsregeln verwendet. Die für die Berechnung verwendeten Datenquellen sind im Anhang zu diesem Dokument aufgeführt. Eine ausführliche Dokumentation aller in EcoTransIT genutzten Datenquellen ist ebenfalls eine ausführliche Beschreibung zur methodischen Vorgehensweise findet sich im wissenschaftlichen Grundlagensbericht (<http://www.ecotransit.org/basis-en.html>).



**Carbon emission and air pollutants**  
 Die Norm EN 16258 enthält keine methodischen Vorgaben zur Berechnung der CO<sub>2</sub>- und Luftschadstoffemissionen. Für eine bessere Vergleichbarkeit wurden die nachfolgenden Emissionen pro Tonne nach der gleichen methodischen Vorgehensweise ermittelt. Weitere Informationen zur Berechnung finden sich im wissenschaftlichen Grundlagensbericht (<http://www.ecotransit.org/basis-en.html>).

**Carbon dioxide**

Mode	CO <sub>2</sub> (kg/100kg)
Truck	19,9
Sea ship	1,3
<b>Total</b>	<b>21,2</b>




**Sulfur dioxide**

Mode	SO <sub>2</sub> (kg/100kg)
Truck	0,001
Sea ship	0,001
<b>Total</b>	<b>0,002</b>




**Nonmethane hydrocarbon**

Mode	NMHC (kg/100kg)
Truck	0,001
Sea ship	0,001
<b>Total</b>	<b>0,002</b>




**Nitrogen oxides**

Mode	NO <sub>x</sub> (kg/100kg)
Truck	0,001
Sea ship	0,001
<b>Total</b>	<b>0,002</b>



**Particulate matter**

Mode	PM <sub>10</sub> (kg/100kg)	PM <sub>2.5</sub> (kg/100kg)
Truck	0,001	0,001
Sea ship	0,001	0,001
<b>Total</b>	<b>0,002</b>	<b>0,002</b>



**Appendix: Documentation of the sources according to the EN 16258**

Die folgende Tabelle gibt in Übereinstimmung mit der Norm EN 16258 einen Überblick über die verwendeten Datenquellen (individuelle Messwerte, spezifische Werte des Transportdienstleisters, Formulare des Transportdienstleisters, Vergleichswerte) sowie über die verwendeten Datenquellen. Eine ausführliche Dokumentation der Datenquellen findet sich im wissenschaftlichen Grundlagensbericht (<http://www.ecotransit.org/basis-en.html>). Wurde die Vorgehensweise in EcoTransIT geändert, wird in der folgenden Tabelle "kündenspezifischer Wert" ausgedrückt.

Parameter	Source	Unit	Method	Notes
Energy and GHG emission factors	EN 16258	EN 16258	EN 16258	EN 16258



**EcoTransIT World entries**  
 Input mode: Forward  
 Ferry routing: Normal  
 Version ETW: 14081 (2014.11.11 16:30:45)  
 Version data base: 14075 (2014.12.11 16:30:45)



**Appendix: Documentation of the sources according to the EN 16258**

Parameter	Source	Unit	Method	Notes
Energy and GHG emission factors	EN 16258	EN 16258	EN 16258	EN 16258



**Appendix: Documentation of the sources according to the EN 16258**

Parameter	Source	Unit	Method	Notes
Energy and GHG emission factors	EN 16258	EN 16258	EN 16258	EN 16258

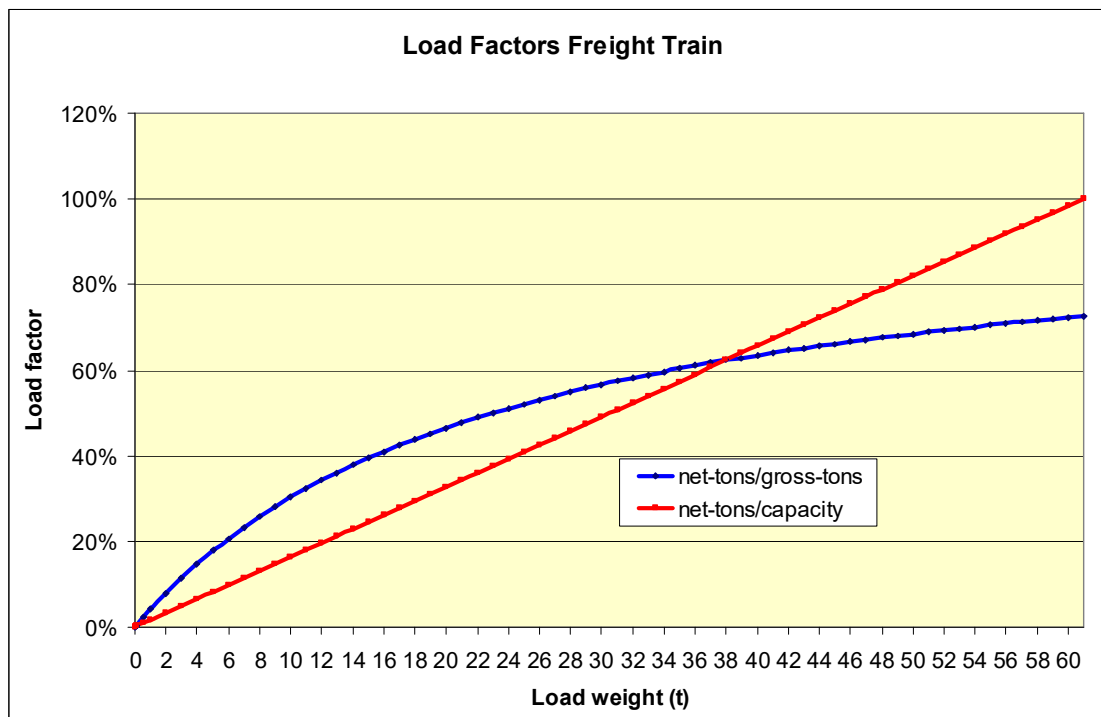
# 7.3 Additional information to load factors

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

### 7.3.1 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 24 Load factors for freight trains



### 7.3.2 Container

Many cargoes shipped in containers are light weight consumer goods<sup>14</sup>. 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

<sup>14</sup> 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.

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 61).

#### **Average cargo:**

In accordance with the Clean Cargo Working Group (CCWG) the net weight of average goods is 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 TEU<sup>15</sup>. Thus, for each lift<sup>16</sup> an average of 1.7 TEUs is loaded. The average empty weight of a TEU is 1.95 tonnes<sup>17</sup>.

#### **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 %<sup>18</sup> to its weight carrying capacity is assumed to represent a light weight cargo container. These results in 6.0 tonnes/TEU and an average empty container weight of 1.9 tonnes.

#### **Heavy weight cargo:**

The default heavy weight TEU load is derived similarly. Here 90 % of the maximum carrying capacity of the containers is assumed to represent the heavy weight cargo. 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

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

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

<sup>17</sup> Calculated from a mix of 20' and 40' containers.

<sup>18</sup> 50 % of the container weight capacity utilised to a maximum of 90 %.

and 7 containers, a ratio of 3x 40' containers filled with volume weight cargo and 2x 40' containers plus 2x 20' containers filled with heavy weight cargo result in the overall average weight of 10.5 tonnes. The heavy weight containers are then filled with 14.5 tonnes per TEU on average<sup>19</sup> 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 61: 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.

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 13 provides the values used in ETW.

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<sup>19</sup> Assuming a maximum utilisation by weight of 90 %.

## 7.4 Detailed data of aircrafts included in EcoTransIT

Table 62 Design range, payload and seats of selected types of aircrafts

Type	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

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## 9 Expressions and abbreviations

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	
M	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
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