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Ecological Transport Information Tool for Worldwide Transports

Methodology and Data
2nd Draft Report

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1 Background and task

Global trade and transport of goods has become as a matter of course the basis of our modern way of life. However, transport wastes limited natural resources and significantly contributes to a major challenge of the 21st century: Global warming. More than a quarter of the worldwide CO_2-emissions are caused by the transport sector, with a tendency to growing faster than in any other sector. The way we organize the increasing logistic flows is therefore gaining importance.

Against this background EcoTransIT World addresses to

- 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 that are interested in a thorough environmental comparison of logistic concepts including all transport modes (railway, lorry, ship, airplane and combined transport).

EcoTransIT World means Ecological Transport Information Tool – worldwide. 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 is the solution with the lowest impact.

The environmental parameters covered are energy consumption, green house gas emissions and air pollutants such as nitrogen oxides (NO_x), sulphur dioxide (SO_2), non-methane hydro carbons (NMHC) and particles.

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

For the first time EcoTransIT was published in 2003 with the regional scope limited to Europe. The recent version in 2010 is EcoTransIT World, which for first time allows calculating environmental impacts of world wide transports. For this purpose the routing of the tool as well as the information about environmental impacts of all transport modes, in particular sea and air transport, was expanded.

The internet version of EcoTransIT as well as the integrated route planner for all transport modes have been realised by IVE/RmCon Hannover. The basic methodology and data for the environment calculations have been developed by IFEU Heidelberg and Öko-Institut.

Originally, EcoTransIT World was initiated by a railway consortium. Today it includes six railway undertakings, the International Union of Railways (UIC) and one logistic provider. In future the consortium aims at including players from all modes thus offering with EcoTransIT World a ‘best-practice’ standard of carbon foot-printing and green accounting to the whole sector – compliant with international standards.

The following report summarizes the methodology and data of EcoTransIT World.

2 System boundaries and basic definitions

2.1 Environmental impacts

Transportation has various impacts on the environment. These have been primarily been 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:

1. Resource consumption
2. Land use
3. Greenhouse effect
4. Depletion of the ozone layer
5. Acidification
6. Eutrophication
7. Eco-toxicity (toxic effects on ecosystems)
8. Human toxicity (toxic effects on humans)
9. Summer smog
10. 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 transports on a quantitative basis. Therefore in EcoTransIT World the selection of environmental performance values had to be limited to a few but important parameters. The selection was made according to the following criteria:

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

The following parameters for environmental impacts of transports were selected:

Table 1 Environmental impacts included in EcoTransIT World

Abbr.	Description	Reasons for inclusion
PEC	Primary energy consumption	Main indicator for resource consumption
CO_2	Carbon dioxide emissions	Main indicator for greenhouse effect
CO_2e	Greenhouse gas emissions as CO_2-equivalent. CO_2e is calculated as follows (mass weighted): $CO_2e = CO_2 + 25 * CH_4 + 298 * N_2O$ CH_4: Methane N_2O: Nitrous Oxide For aircraft transport the additional impact of flights in high distances can optionally be included (based on RFI factor)	Greenhouse effect
NOx	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
SO_2	Sulphur dioxide emissions	Acidification, eco-toxicity, human toxicity
NMHC	Non-methane hydro carbons	Human toxicity, summer smog
Particles	Exhaust particulate matter from vehicles and from energy production and provision (power plants, refineries, sea transport of primary energy carriers), in EcoTransIT World particles are quatified 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 are also not considered. **PM emissions** are defined as exhaust emissions from combustion, therefore PM emissions from abrasion and twirling are not included so far.

Location of emission sources

Depending on the impact category, the location of the emission source can be highly significant. With regard to those emissions which contribute to the greenhouse effect, the location for land bound transport modes is not relevant, whereas flights in high altitudes have additional climatic impacts. Therefore in EcoTransIT World these additional impacts are included as an option for flights in altitudes over 9 kilometres by using the RFI factor (see chapter 5.5).

Regarding eco-toxicity and human toxicity the following locations of the emission source are relevant for the impact.

- Road, rail and inland ship: urban vs. rural regions
- Aircraft: airport (taxi out/in, lake off, landing) vs. cruise
- Sea ship: harbour and coast vs. open sea.

In EcoTransIT World this distinction is not yet made, as it would complicate the interpretation of the results in the current version of the tool. It should be part of a future version.

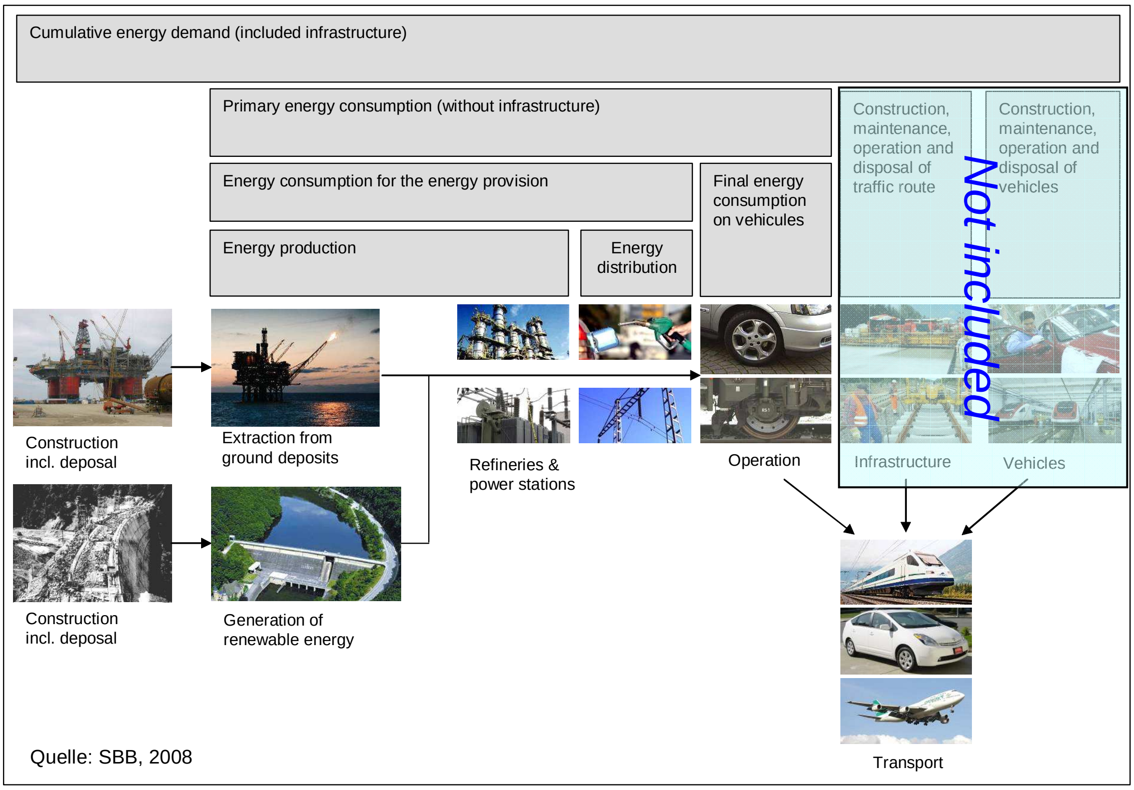
2.2 System boundaries of processes

In EcoTransIT World, only those environmental impacts are considered that are linked to the operation of vehicles and to fuel production. Therefore not included are:

- 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 1 System boundaries of processes



Quelle: SBB, 2008

In EcoTransIT World two process steps and the sum of both are distinguished:

- **final energy consumption** and **vehicle emissions** (= operation)
- **upstream energy consumption** and **upstream emissions** (= energy provision, production and distribution)
- **total energy consumption** and **total emissions**: Sum of operation and upstream figures

2.3 Transport modes and propulsion systems

Transportation of freight is performed by different transport modes. Within EcoTransIT World 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
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 / marine diesel oil /marine gas oil
Aircraft transport	Air planes (different types)	Kerosene

2.4 Spatial differentiation

In EcoTransIT World wordwide transports are considered. Therefore environmental impacts of transport can be diverse in different countries due to country specific regulations, energy conversion systems (e.g. energy carrier for electricity production), traffic infrastructure (e.g. share of motorways and electric railtracks) and topography.

Special conditions are relevant for the international transport with sea-ships. Therefore a spatial differentiation is not necessary. For sea transport a distinction is made for different trade lanes. In contrast for aircraft transport the conditions which are relevant for the environmental impact are similar all over the world.

Road and rail

For road and rail transport EcoTransIT World distinguishes in Europe between countries. In this version of EcoTransIT World it was not possible to find accurate values for the transport systems of each country wordwide. For this reason we defined seven world regions and within the regions we identified the most important countries with high transport performance which were individually considered. 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				

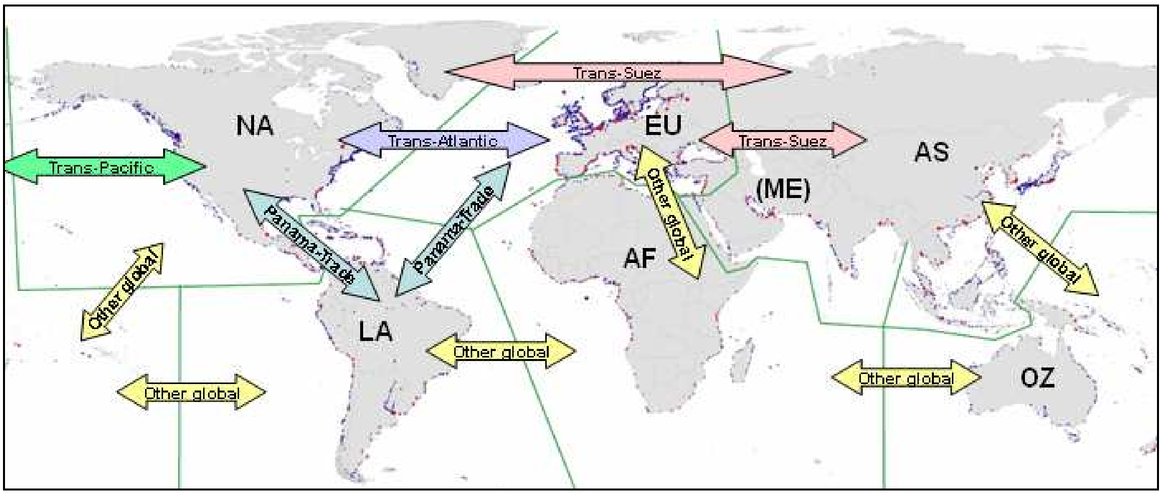
Significant influencing factors are the types of vehicles used, and the type of energy carriers and conversion used. Wide variations result particularly from the national mix of electricity production.

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 this project it was not possible to determine specific values for railway transport for all countries. Therefore a country specific differentiation of the specific energy consumption of cargo trains was not carried out.

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 a database containing the globally registered and active ships /Lloyds 2009/. For each intercontinental (e.g. North America to Europe) or major inter-regional (North-America to South-America) trade lane the common size of deployed ships was analyzed, using schedules from ocean carriers. The trade-lane specific emission factors where then aggregated from the global list using the trade lane specific vessel sizes. Figure 2 shows the connected world regions and the definition of EcoTransIT World marine trade-lanes. The considered regions are NA – North Amerika, LA – South Amerika, EU – Europe, AF – Afrika, AS – Asia and OZ – Ozeanien

Figure 2; EcoTransIT World division of the world oceans and definition of major trade lanes.



For inland ships the differentiation was only made between two size classes based on the UNECE code for Inland waterways /UNECE 1996/. European rivers were categorized in two size classes (smaller class V and class V and higher) and vessels were allocated to those classes according to the ability of navigating on those rivers. For North America the class V and higher was used. No data was available for particular specifications for inland ships in other world regions than Europe and North America. EcoTransIT World assumes the deployment inland vessels comparable to class V and larger on all other relevant inland waterways. It is assumed that differences may exist with regard to fuel sulphur levels, but that energy consumption data likely apply to those regions as well. Overall only a minor role of inland shipping is assumed for regions other than Europe and North America justifying the generalisation.

Overview of country and mode specific parameters

The following table summarizes all country or region and mode specific parameter.

Table 4 Parameter characterisation

	Country/region specific parameter	Mode specific parameter
Road	Fuel specifications: - Sulfur content - Carbon content - Share biofuels Emission regulation Topography Available vehicles (heavy vehicles allowed?) Default vehicles for long-distance/feeder	Truck types: - Final energy consumption - Emission factors (NOx, NMVOC, PM, N_2O, CH_4)
Rail	Exhaust emission factors for diesel traction (NOx, NMVOC, PMexhaust, N2O, CH4 Fuel specifications: - Sulfur content - Carbon content - Share biofuels Energy and emission factors of upstream process Topography Available train types (heavy trains allowed?) Default vehicles for long-distance/feeder	Train weight and energy carrier: Final energy consumption (functions)
Inland Ship	European and North American fuel specification. Inland ship size classes. River classification according to the European system.	Final energy consumption Emission factors (NOx, NMVOC, PM, N_2O, CH_4) Vessel size classes Type of vessels Bulk and containerized transport
Sea Ship	Differentiation between at-sea and in-port emissions. Categorization of major trade lanes. Fuel specification differentiated for global trade, for trade within Sulphur Emission Control Areas (SECA) and for engine activity within ports according to legislative requirements..	Vessel types by: - Bulk and container vessels. - Size-class - Aggregated for trade-lanes. - Special locations (SECA) Final energy consumption Reduced speed adjustment option Emission factors (NOx, NMVOC, PM, N_2O, CH_4)
Aircraft	-	Aircraft type: - Final energy consumption - Emission factors (NOx, NMVOC, PM, N_2O, CH_4)

3 Basic definitions and calculation rules

This chapter gives an overview of basic definitions, assumptions and calculation rules for freight transport used in EcoTransIT World. The focus will be 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 5.

3.1 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 specific importance:

- 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 EcoTransIT World parameters with high influence on energy consumption and emissions can be changed in the expert mode by the user, some others 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 mode, expert mode, routing) in EcoTransIT World.

Table 5 Classification and mode (standard, expert, routing) of main influence factors on energy consumption and emissions in EcoTransIT World

Sector	Parameter	Road	Rail	Sea ship	Inland Ship	Aircraft
Vehicle, Vessel	Type, size, payload capacity	E	E	E	E	E
	Drive, energy	A	E	A	A	A
	Technical and emission standard	E	A	A	A	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	S	S	S	S	S

Remarks: A = included in average figures; S = selection of different categories or values possible in the standard mode, E = selection of different categories or values possible in the expert mode, R = selection by routing algorithm; empty = not relevant

3.2 Logistic parameters

Vehicle size, payload capacity and capacity utilisation are the most important parameters for the environmental impact of freight transports, which quantify the relation between the freight transported and the vehicles/vessels used for the transport. Therefore EcoTransIT World gives the possibility to adapt these figures in the expert mode.

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 coal, ore, oil and some chemical products. Typical products with volume as the limiting factor are vehicle parts, clothes and consumer articles. Volume limited freight normally has a specific weight of the order of 200 kg/m^3 /Van de Reyd and Wouters 2005/. It is evident that volume restricted goods need more transport vessels and in consequence e.g. 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 an increased fuel consumption.

Marine container vessels behave slightly different with regard to cargo weight and fuel consumed. 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.

3.2.1 Definition of payload capacity

In EcoTransIT World 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 Word, however it is not visible because TEU-based results are finally converted to tonnes of freight (see also chapter 3.2.2):

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 and other stuff). In EcoTransIT World 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 railroad line. International railroad lines normally are dimensioned for more than 20 tonnes per axle (e.g. railroad 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 is used with different sizes, for different cargo types and logistic activities. However, the most important influence factor for energy consumption and emissions is the relation between payload and total weight of the wagon (see chapter 3.2.2). Therefore in EcoTransIT World a typical average wagon is defined, based on wagon class UIC 571-2 (Ordinary class, four axles, type 1, short, empty weight 23 tonnes, /Carstens 2000/). The payload capacity of 61 tonnes was defined by railway experts within the EcotransIT consortium. 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.

Table 6 Definition of standard railway wagon in EcoTransIT World

No of axles	Empty weigh [tonnes]t	Payload capacity [tonnes]	Max. axle load [tonnes]
4	23	84	21
Source: Carstens 2000, IFEU assumptions			

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 EcoTransIT World.

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. Typical capacities of freighters are between around 15 tonnes for small aircrafts and over 100 tonnes for large aircrafts. Passenger airplanes have a limited payload capacity for freight between around 1-2 tonnes for small aircrafts and 25 tonnes for large aircrafts. For more details see chapter 5.5.

Freight in Container

EcoTransIT World allows the calculation of energy consumption and emissions for container transport in the expert mode, based on the unit "Number of TEUs" (Twenty Foot Equivalent Unit). For the calculation TEU is transformed into tonnes.

Containers come in different lengths, most common are 20' (= 1 TEU) and 40' containers (= 2 TEU), 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.

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

Table 7: Dimensions of the standard 20' and 40' container.

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/TEU (40' container) and 21.75 t/TEU (20' container). Special containers, for example for carrying liquids or open containers may differ from those standard weights. I

Payload capacity for selected vehicles and vessels

In the expert mode, a particular vehicle and vessel size class and type may be chosen. For land-based transports those 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. “like handysize” (~ = like).

The following table shows key figures for empty weight, payload and TEU capacity of different vessel types in EcoTransIT World. 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 ships typically found on rivers of class IV to VI.

Table 8 Empty weight and payload capacity of selected transport vessels

Vehicle/ vessel	Vehicle/vessel type	Empty weight [tonnes]	Payload capacity [tonnes]	TEU capcity [TEU]	Max. total weight [tonnes]
Truck	24-40 gross tonnes	14	26	2	40 (44)
	12-24 gross tonnes	10	12	1	24
	7.5-12 tonnes	6	6	-	12
	<=7.5 tonnes	4	3.5	-	7.5
Train	Standard wagon	23	61	4	84
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>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)	110	650		
	Europe-ship (class IV)	230	1,350		
	RoRo (class Va)	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 737-200C	28.3	17.3	-	45.6
	B767-300F	86.5	53.7	-	140.2
	B747-400F	164.1	112.6	-	276.7

Remarks: Max. total weight for Ship = DWT (Dead weight Tonnage), for Aircraft = Take off weight:
*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

3.2.2 Definition of capacity utilisation

In EcoTransIT World 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	[tonne]
LF_{NC}	Load Factor: mass of weight / payload capacity $LF_{NC} = M / CP$	[net tonnes/tonne capacity]; [%]
ET	Empty trip factor: Additional distance the vehicle/vessel runs empty related to loaded distance allocated to the transport. ET = Distance empty / Distance loaded	[km empty/km loaded], [%]

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

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

Capacity utilisation for trains

For railway transport the load factor in the given definition is often no figure which is statistically available. 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 EcoTransIT World capacity utilisation is needed as input. For energy and emission calculation capacity utilisation is transformed to net-gross-relation according the following rules:

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

In EcotransIT World empty wagon weight and payload capacity of rail wagons are defined (see chapter 3.2.1), thus the formula for the transformation of capacity utilisation into net-gross-relation is:

Abr	Formula	Unit
CU_{NG}	$CU_{NG} = CU_{NC}/(CU_{NC} + 23/61)$	[net tonnes/gross tonne]

3.2.3 Capacity Utilisation for specific cargo types

The former chapter described capacity utilisation as an important parameter for the energy and emission calculation. 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
- Amount of empty kilometre 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 EcotransIT World 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 9 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, necessitate 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.

Containerized sea and intermodal transport: For containerized sea transport the bulk, average and volume goods have been translated into freight loads of one TEU. A full container is assumed to be reached at 16.1 t net weight and 18.1 t gross weight per TEU, corresponding to 100 % load. 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 10 provides the values used in EcoTransIT World as well as the formula for calculating cargo loads in containers. For more details see appendix chapter 6.1.

Table 10 Weight of TEU for different types of cargo

	Container [tonnes /TEU]	Net weight ([tonnes/TEU]	Total weight [tonnes/TEU]
Bulk	2.0	14.5	16.50
Average	1.95	10.5	12.45
Volume	1.9	6.0	7.90
Source: assumptions Öko-Institut			

Capacity utilisation for road and rail transport

The load factor for the “average cargo” of different railway companies are in a similar range of about 0.5 net-tonnes per gross-tonne /Railway companies 2002a/. The average load factor in long distance road transport with heavy trucks was 50 % in 2001 /KBA 2002a/. These values include also empty vehicle-km. The share of additional empty vehicle-km in road traffic was about 17 %. The share of empty vehicle-km in France was similar to Germany in 1996 (/Kessel und Partner 1998/).

No data for the empty vehicle-km in regards to rail transport is available. 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 specialised rail cars. 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 goods 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 are 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 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. The assumptions are summarised in Table 11.

Table 11 Capacity utilisation of road and rail transport for different types of cargo

	Load factor LF_{NC}	Empty trip factor ET	Capacity utilisation CU_{NC}	Relation Nt/Gt CU_{NG}
Train wagon				
Bulk	100%	80%	56%	0.60
Average	60%	50%	40%	0.52
Volume	30%	20%	25%	0.40
Truck				
Bulk	100%	60%	63%	
Average	60%	20%	50%	
Volume	30%	10%	27%	
Source: IFEU estimations				

Capacity utilisation for ocean going vessels

Capacity utilisation for sea transport is differentiated per vessel type. Most significantly is the differentiation between bulk vessels and container vessels, which operate in liner services. The operational cycle of both transport services lead to specific vessel utilization factors.

The vessel utilization for bulk and general cargo vessels is assumed to be between 48 % and 61 % and follows the IMO assumptions /Buhaug et al. 2008/. 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. However, cycles can multi-angular and sometimes opportunities to carry cargo in both directions may exist. The utilization factors are listed in Table 35 on page 57.

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 (Figure 3). It is also common that the route is chosen to optimize the cargo space utilization according to the import and export flows. For example, on the US West Coast a particular pattern exist 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 major food exports then leave the United States. Liner schedules have not been considered in EcoTransIT World, but may be considered in later versions.

Figure 3: Sample Asia North America Trade Lane by Hapag-Lloyd AG. (Internet Site from 28.10.2009)

Utilization factors for container ships (load of container spaces on vessels and empty returns) were derived by assuming an average maximum container vessel utilization of 85 % on the fuller of the two legs. This results in a general average vessel utilization factor of 65 %, averaged over the return journey. Only for large container vessels above 7000 TEU a maximum load of 90 % and a global average of 70% was assumed.[1] Vessel utilization factors may be altered in the expert modus of the tool. Some guidance on further differentiating utilization factors on the major trade lanes is given in the appendix in Chapter 6.3.

Capacity utilisation for inland vessels

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 utilization 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 utiliza-

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[1] This differs from assumptions made by the 2009 IMO study. However, the assumptions presented by Buhaug et al. /2008/ on container vessel utilization, main engine load and average load of containers are not plausible. The problem with the IMO figures are that they present the data based on t-km. Ocean carriers themselves prefer to present their emission factors based on TEU-km (BSR 2010). Our assumption is that /Buhaug et al. 2008/ applied a relatively high vessel utilization factor and low engine load but then combined it with a low container load of only 7 tonnes per TEU. Thus, studying trade flows and container loads have lead us to different conclusions, although finally the resulting emission factors come very close to those published by the IMO

tion.

Container inland vessels were assumed to have a vessel utilization of 70 % in analogy with the average container vessel utilization cited in /Buhaug et al. 2008/. This reflects less than full loads of containers as well as the better opportunity of container vessels to find carriage for return trips in comparison with bulk inland vessels.

Capacity utilisation of air freight

Since mainly high value volume or perishable goods are shipped by air freight the permissible maximum weight is limited. Therefore only the category volume goods is considered and 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) /DEFRA 2008; Lufthansa 2009/. The capacity utilisation for freight refers to the maximum weight which can be transported by freighter or passenger aircraft. For air traffic the capacity utilisation is identical with the load factor because empty trip factor is zero. The load factor for passenger included in Table 12 provides information about the seats sold. The latter is used for the allocation of energy consumption and emissions between air cargo and passenger (see chapter 5.5).

Table 12 Capacity utilisation of freight and passenger for aircrafts

	Freight (freighters and passenger aircrafts	**Passenger** (only passenger aircrafts)
Short haul (up to 1,000 km)	55%	65%
Medium haul (1,001 – 3,700 km)	60%	70%
Long haul (more than 3,700 km)	65%	80%
Sources: DEFRA 2008; Lufthansa 2009.		

Further information about the definition of capacity utilisation and TEU can be found in the appendix chapter 6.1.

3.3 Basic calculation rules

In EcotansIT World the total energy consumption and emissions of each transport mode are calculated for vehicle usage and the upstream process (efforts for production and delivery of final energy carriers, see chapter 2.2). Thus several calculation steps are necessary:

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

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 data base are given in Chapter 5.

3.3.1 Final energy consumption per net tonne km

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

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

The corresponding **formula** is

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

Abbr.	Definition	Unit
$ECF_{tkm,i}$	Final energy consumption 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 is the most important key figure for the calculation of total energy consumption and 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 are needed for each energy carrier.
- Final energy consumption depends on various factors (see chapter 3.1). In particular it should be pointed out that e.g. final energy consumption per kilometre for trucks depends also from capacity utilisation and thus from denominator of the formula.
- The formula 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 5). However, for all modes the same relevant parameters (final energy consumption of vehicle/vessel, payload capacity and capacity utilisation) are needed.

3.3.2 Combustion related emissions per net tonne km

The principle **calculation rule** for the calculation of NOx, NMHC, particles, CH_4 and N_2O emissions (so called combustion related emissions) is

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

The corresponding **formula** is

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

Abbr.	**Definition**	**Unit**
$EMV_{tkm,i}$	Vehicle emissions consumption per net tonne km for each energy carrier i	[g/tkm]
I	Index for energy carrier(e.g. diesel, electricity, HFO)	
$EMV_{km,i,}$	Combustion related vehicle emission factor 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 3.3.3.

3.3.3 Energy related emissions per net tonne km

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

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

The corresponding formula is

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

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

Explanations:

- The formula is used for all emission components which are directly correlated to final energy consumption (CO_2 and SO_2) and for combustion related emissions of fuel driven trains and ships (see chapter 5.2 to 5.4).
- For trucks and aircrafts combustion related emissions are calculated with the formula in chapter 3.3.2

3.3.4 Upstream energy consumption and emissions per net tonne km

The principle calculation rule for the calculation of vehicle emissions is

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

The corresponding formulas are

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

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

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

Expanations:

- Formulas for upstream energy consumption and emissions are equal, but have different units.
- Formulas are equal for all transport modes; upstream energy consumption and emissions factors used in EcoTransIT World are explained in chapter 5.6

3.3.5 Total energy consumption and emissions of transport

The principle calculation rule for the calculation of vehicle emissions is

Total energy consumption or emissions per transport =
Transport Distance
* mass of freight transported
* (final energy consumption or vehicle emissions per net tonne km
\+ upstream energy consumption or emissions per net tonne km)

The corresponding formulas are

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

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

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

Explanations:

- Transport distance is a result of the routing algorithm of EcoTransIT World (see chapter 4).
- 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 expert mode of EcoTransIT World.

3.4 Basic allocation rules

EcoTransIT World is a tool intended to be used by shippers – the owner of a freight that is to be transported – that want to estimate the emissions associated with a particular transport activity or a set of different transport options. It may be also used by carriers – the operators and responsible parties for operating vehicles and vessels – to estimate emissions for benchmarking. However the perspective is that of a shipper and the calculation follows principles of life cycle assessments (LCA) and carbon footprinting.

The major rule is that the shipper (freight owner) takes responsibility for the vessel utilization 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.

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. The 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 EcoTransIT World to provide the possibility of modal comparisons. This also requires that all transport modes are equally treated. Thus, average freight utilization and average emissions without directional deviations are considered. Therefore, in EcoTransIT World the option with inland vessels to calculate up-river and down-river was deleted as well.

In EcoTransIT World energy and emissions are calculated for the transport 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 is 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 expert 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 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

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.

4 Routing of transports

4.1 General

For the calculation of energy consumption and environmental impacts EcoTransIT World has to determine the route between origin and destination for each selected traffic type. Therefore EcoTransIT World uses in the background a huge geo-information database including world wide networks for streets, railways, aviation, sea and inland waterways.

4.2 Routing with resistances

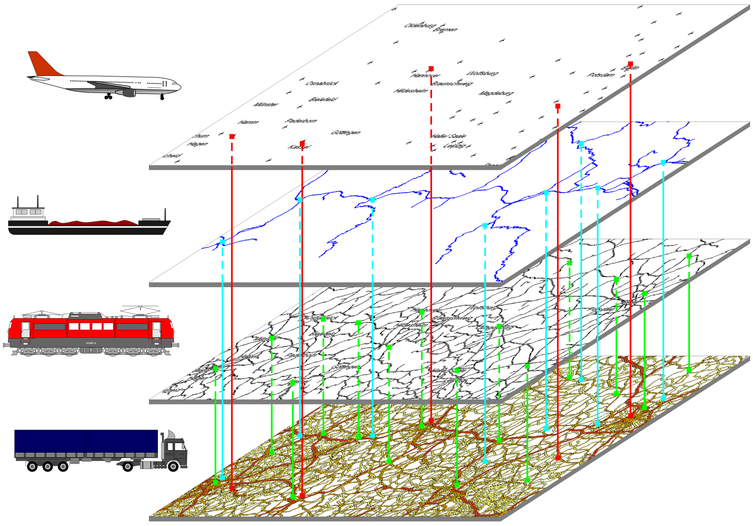
Depending on the transport mode type and the individual settings EcoTransIT World routes the shortest or the “fastest” way. For the fastest route EcoTransIT splits the respective network into different route classes like the streets into highway to city-street. If there is a motorway between the origin 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 EcoTransIT World. Technically spoken a motorway has a much lower resistance (factor 1,0) than a city-street (factor 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.

4.3 Routing via different networks

The routing takes place on different networks, which are streets, railway tracks, airways, inland waterways and sea ship routes. Depending on the selected mode, EcoTransIT routes on the respective traffic type network. All networks are connected with so called transit edges. These transit edges enable the routing algorithm to change a network if this is needed.

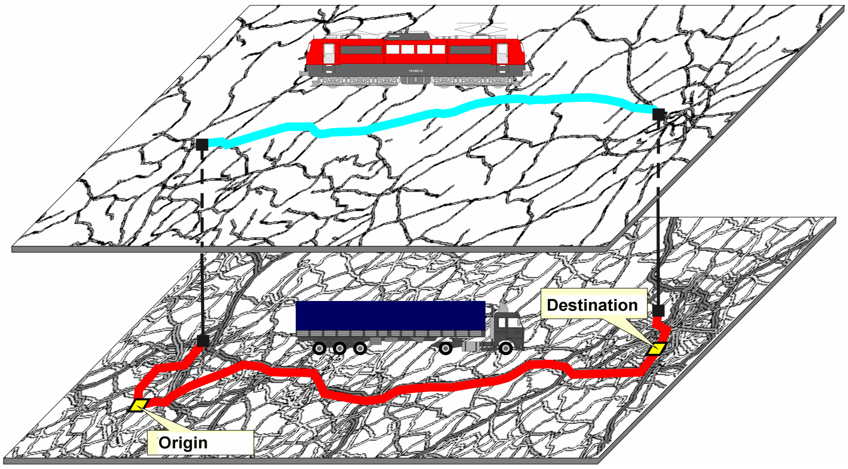
This happens if the user wants to route an air plane but selects city names as origin and destination instead of an airport. In this case EcoTransIT has to determine the closest airport situated to the origin and destination and automatically routes via the street network to these airports. The main routing between the two airports takes place on the air network. The transit nodes enable the change from and to every network.

Figure 4 Principle of nodes between different networks



If a change of the network is needed, EcoTransIT always uses the geographically nearest transit node (e.g. station, airport, harbour). This can sometimes create not realistic routes because the geographical closest harbor could not be the best choice if e.g. then the ship has to go around a big island. To avoid this it is recommended to select the transit node directly in the front-end as a via node.

Figure 5 Route selection in road and rail network from origin to destination



Every traffic type uses different routing parameters which where stored as attributes within the GIS-data.

4.3.1 Truck network attributes

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

Table 13 Resistance of street categories

Street category	Resistance
Motorway (Category 0)	1,0
Highway (Category 1)	1,3
Big city street (Category 2)	2,4
City street (Category 3)	3,5
Small city street (Category 4-6)	5,0

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. EcoTransIT has different resistances for ferry routes included.

Table 14 Resistance for ferries in the road network

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

4.4 Railway network attributes

Railways have the attributes electrified or diesel line and dedicated freight corridor as attributes. 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

Atribute	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. EcoTransIT 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

4.5 Air routing

In EcoTransIT there is a validation if the selected air port is suitable for the flight. Therefore all airports are categorized. Depending on the category of the airport destinations at 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 oversea)
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 is based on 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.

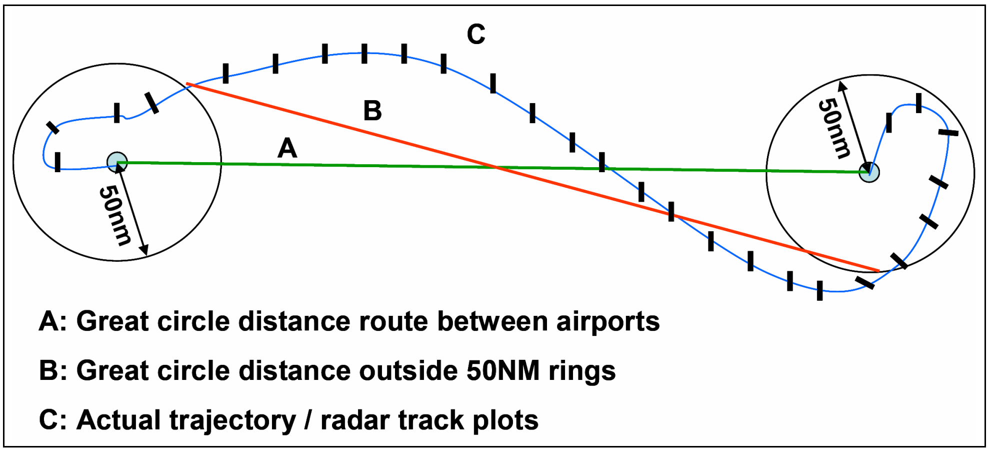
However, the real flight path is longer than the GCD due to departure and arrival procedures, stacking, adverse whether conditions, restricted or congested airspace /Kettunen et al. 2005, Gulding et al. 2009, Reynolds 2009/. Detailed analyses show that within a circle of 50 nautic miles (92.6 km) around the airports the detour is around 30 km /Reynolds 2009/. The en-route deviation between the airport areas lies between 2 and 8% of the GCD /Reynolds 2009/. An average value for U.S. airports is 3 %, whereas the European average is 4 % /Gulding et al. 2009/. For this reason the real flight distance is calculated by using the following formula:

$$\boxed{\text{Real flight distance} = (\text{GCD} - 185.2\text{ km}) \times 1.04 + 185.2\text{ km} + 60\text{ km}}$$

If the spherical distance between the to airports is smaller 185,2 kilometers than:

$$\boxed{\text{Real flight distance} = \text{GCD} + 60\text{ km}}$$

Figure 6 Comparison of actual trip distance and great circle distance /Kettunen et al. 2005/



The maximum reachable distance is defined by the largest air plane type (Boing 747-400). If the distance between two airports is larger than the airplane can reach the route will not be found. This can happen e.g. if the user wants to calculated a trip from New York to Sydney. In the expert mode the user of EcoTransIT have to insert a stopover airport. To avoid this problem in the standard mode a long haul plane (Boeing747-400) is included in EcoTransIT that has no flight limit. If the distance is more than 8,230 kilometers by freighter (maximum distance of the Boeing 747-400 freighter) at half flight distance a theoretical stopover will be added. Thus the route will be enlarged by using this extra via point. If the distance is more than 16,460 kilometers two stopovers will be simulated (the route will be separated into three equal legs.

4.6 Sea ship routing

A sea ship normally takes the direct and shortest way between two harbors, although often deviates slightly from direct routes due to weather and ocean drift conditions. Therefore a very large and flexible network is needed. The solution of this request 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 sea node as long it does not cross a country side. The result of these connections is a sea network on which routes can be found.

Additional to this network the canals and certain sea bottle necks, e.g. the Kattegat strait, are included. Every canal and bottle neck has the attributes “maximum dead weight tons” and “maximum TEUs”. This is important to limit the routing to the respective ship type. On other words depending on the loaded TEUs or dead weight tons a ship can use a canal or not.

Within the EcoTransIT sea ship network the canals Suez, Panama and North-East-Sea are included. Additionally there are small sea areas like Kattegat strait and the entrance to the Great Lakes, which is close to Montreal. These areas are also handled as canals.

Every harbor has a predefined emission area. If start and destination belong to different areas EcoTransIT suggests a ship type suitable for connecting both areas. The emission area is also used for a validation if the selected harbor is suitable for the trip. Therefore all harbors are categorized into three levels (small, medium and big harbor). Depending on the category and the emission area the harbor has different distances that can be reached. If e.g. the harbor is categorized as a small harbor it is only possible to reach targets within the same emission area (Intra-continental shipping). Medium or larger harbors can be used for intercontinental shipping.

4.7 Routing inland waterway ship

The inland waterway network has attributes for the waterway class. Depending on the ship type waterways with the respective waterway class can be used or not. Whereas the euro barge only can be used on inland waterways upper the class IV (standard European inland waterway), bigger barges need at least waterway class V or higher. Compare also with chapter 5.4.1.

4.8 Definition of sidetrack or harbor available

It is also possible to define side tracks and inland waterway edges that are not included in the network yet. In case of the activation EcoTransIT routes on the street network to the next respective location (station at side track and inland harbor at waterway available). This feeder route will then be calculated as the respective transport mode and not as truck. This method is helpful if e.g. the network link to the railway or shipping location is not within the GIS-data but should be calculated with the same transport type. Or if a company has a side track which is not into the GIS-data.

5 Methodology and environmental data for each transport mode

5.1 Road transport

5.1.1 Classification of truck types

EcoTransIT World 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 also other truck types are used. In EcoTransIT World the following gross weight classes are defined which cover all vehicle sizes used for cargo transport:

Table 18 Truck size classes in EcoTransIT World

EU/Japan	EPA
Truck <=7.5t	Truck <=16,000lbs
Truck >7.5-12t	Truck >16,000-26,000lbs
Truck >12-24t	Truck >26,000-60,000lbs
Truck >24-40t	Truck >60,000-80,000lbs
Truck >40-60t	Truck >80,000lbs

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 1 -EURO 5) are used. The Pre-EURO 1-standard is no longer relevant for most long distance transports, and therefore was 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 EcoTransIT World.

Table 19 Emission standards in EcoTransIT World

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

5.1.2 Final energy consumption and vehicle emission factors

The main sources for final energy consumption and vehicle emission factors is the “Handbook emission factors for road transport” (HBEFA) /INFRAS 2010/ for trucks with EU emission limits and the MOVES model for EPA standard /EPA 2009/.

The influence of the **load factor** is modelled according to the Handbook of Emission Factors /INFRAS 2010/. 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. Two typical driving patterns, one for highway traffic and one for traffic on other (mainly extra urban) roads, are considered by EcoTransIT World. Traffic on urban roads has a small fraction in long distance transport and is therefore included in the other roads.

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", "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 transport 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 EcoTransIT World are derived from the Handbook of Emission Factors (HBEFA 3.1) /INFRAS 2010/ for trucks with Euro standard. For the determination of values for truck in North America several sources were analysed:

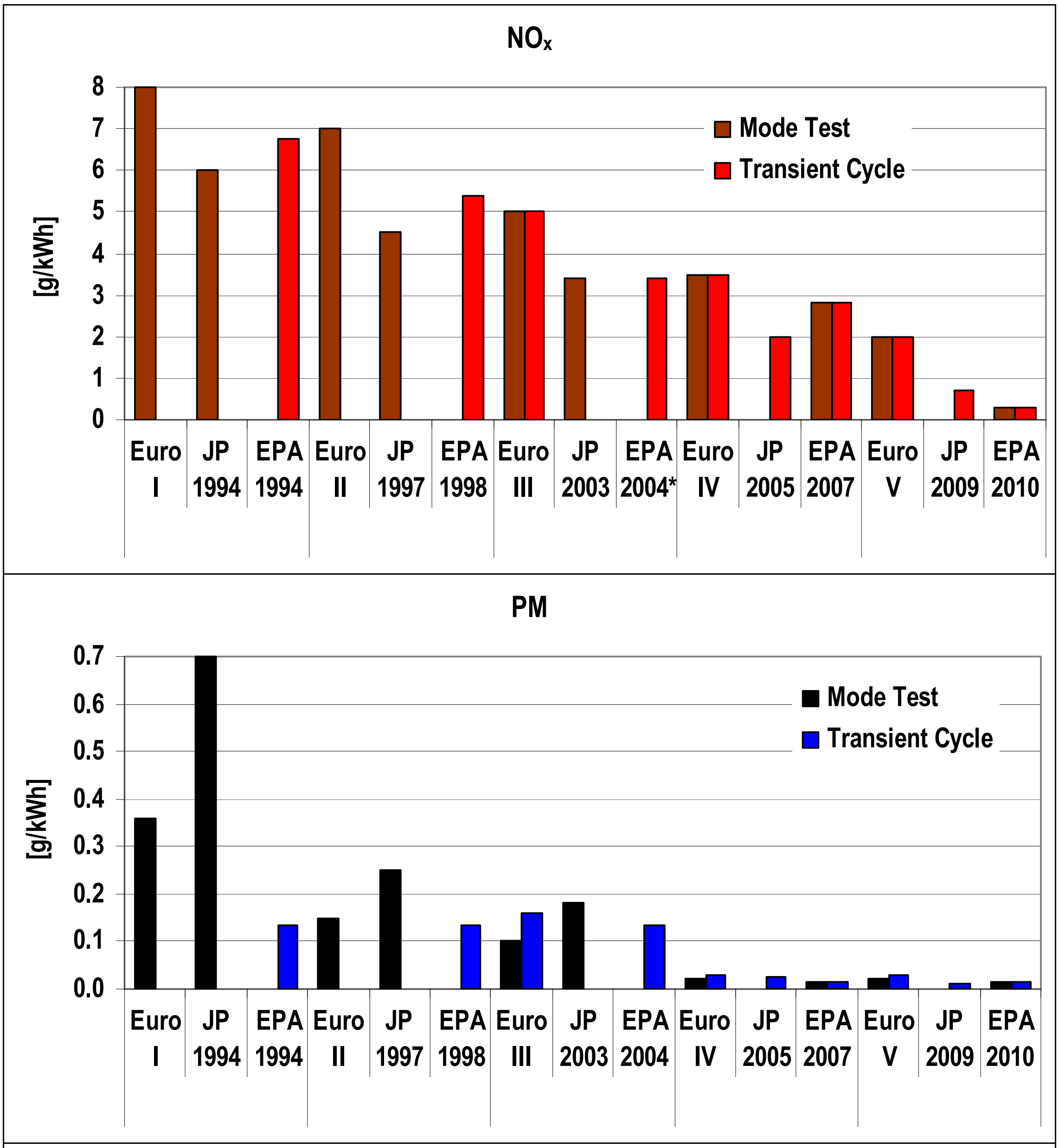
- emission limit values for the EPA standard compared with the EU standard /Dieselnet 2009/
- the emission model MOVES2010 to compare emission factors and energy consumption of trucks by road type, registration year and size /EPA 2009/
- further statistical data (/USCB 2004/, /USDOT 2007/, /USDOE 2009/) on truck size classification, average utilization and energy consumption

Comparison of Emission standards

A comparison of the U.S., EU and Japanese emission limit values provides the first insight into the potential difference of the trucks exhaust emission characteristics between these countries. For particulate matter and nitrogen oxide we conclude:

- because of the difference between the emission limit values, different exhaust emission characteristics of trucks operating in these different regions are assumed
- for PM the previous high difference decreased in the past
- the EU loose their pioneer position of having the most stringent limit values in 2009/2010

Figure 7 EU, Japanese and U.S. Emission Limit Values for Heavy Duty Diesel Vehicles by Emission Standard and Testing Procedure



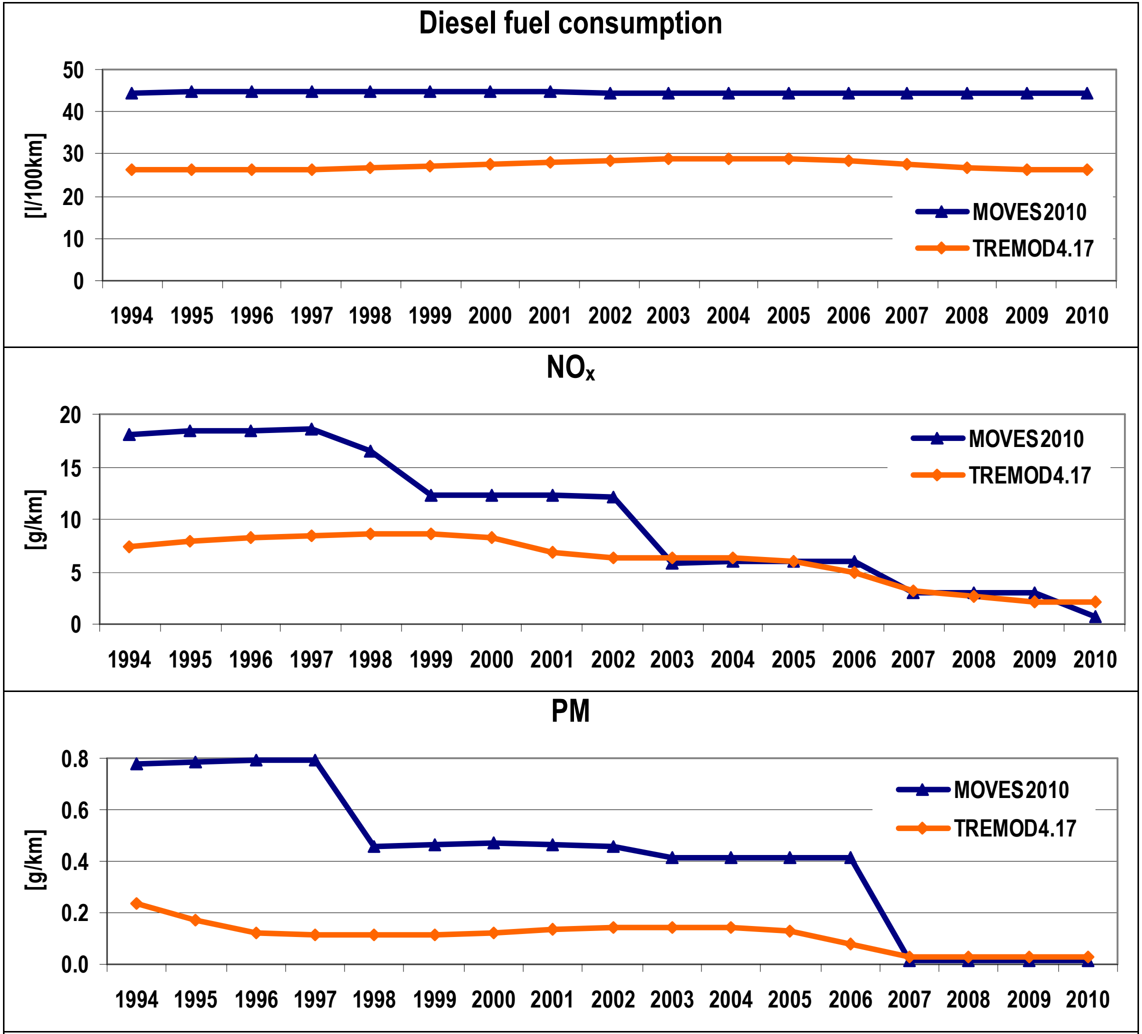
* combined limit value of 3.38 g/kWh NMHC+NOx

Source: /Dieselnet 2009/

Comparison of energy consumption and emission values

The figure below illustrates the differences in environmental between EU and U.S. trucks. The data is based on the U.S. emission model MOVES and the German transport emission model TREMOD /IFEU 2005/.

Figure 8 Specific emission of heavy trucks* in 2010 by registration year – comparison of U.S. (MOVES) and German (TREMOD) emission models data**



* Trucks on motorway; in DE GVW >14t; in U.S. GVW >15t (metric tons)

** based on previous version of /INFRAS 2010/

Sources: /IFEU 2005/; /EPA 2009/

The Handbook Emission Factors for Road Transport HBEFA /INFRAS 2010/ delivers data on specific emission and energy consumption of trucks in 2010 by emission standard, truck size and road type. Unfortunately in the U. S. model MOVES2010 /EPA 2009/ trucks are only classified by road type, truck size and vehicle age, but not by emission standard.

To determine emission factors for U.S. trucks with a classification like in /INFRAS 2010/ we assumed that U.S. trucks in 2010, which were registered in 1994 represent EPA1994 standard, with registration in 1998 represent EPA1998 standard etc.. On the basis of these and further assumptions we estimated the adjusting factors, shown in the table below. Presently we have no information about emission factors or energy consumption of Japanese trucks. Therefore we take the emission factors from Europe for Japanese trucks.

Table 20 Adjusting factors for derivation of energy and emissions factors for North American trucks with EPA emission standard in EcoTransIT World

Emission Standard EPA	Related to Emission Standard	Energy Consumption	NMVOC	NOx	PM
EPA 1994	Euro-I	1.40	1.10	2.10	3.00
EPA 1998	Euro-II	1.40	1.60	1.80	3.30
EPA 2004	Euro-III	1.40	1.10	0.90	3.00
EPA 2007	Euro-IV	1.40	1.30	0.90	0.80
EPA 2010	Euro-V	1.40	1.30	0.40	0.60

Fuel related emission factors

CO_2-emissions depend directly from the fuel properties. In EcoTransIT world for diesel fuel an emission factor of 74,000 kg/TJ is used.

Emission factors for SO_2 are derived from the actual sulphur content of the fuel. The sulphur content of diesel fuel is assumed according the valid legislation. For the EU the value in 2010is 10 ppm in Europe (= 0.47 kg/TJ). In several countries it goes up to 2’000 ppm. The Sulphur content for different countries is shown in the following table:

Table 21 Sulphur content of highway diesel fuel [ppm]

Region	Code	Sulfur-Content [ppm]	Region	Code	Sulfur-Content [ppm]
Africa	default	2000	***Central and South America***	default	2000
	ZA	500		BR	2000
Asia and Pacific	default	2000	***Europe***	default	1000
	CN	2000		TR	1000
	HK	50		EU 27	10
	IN	50		others	10
	JP	10	***North America***	default	15
	KR	50		US	15
Australia	default	10	***Russia and FSU***	default	2000
	AU	10		RU	2000
Sources: /UNEP 2009/; /COM 2005/78/EC/					

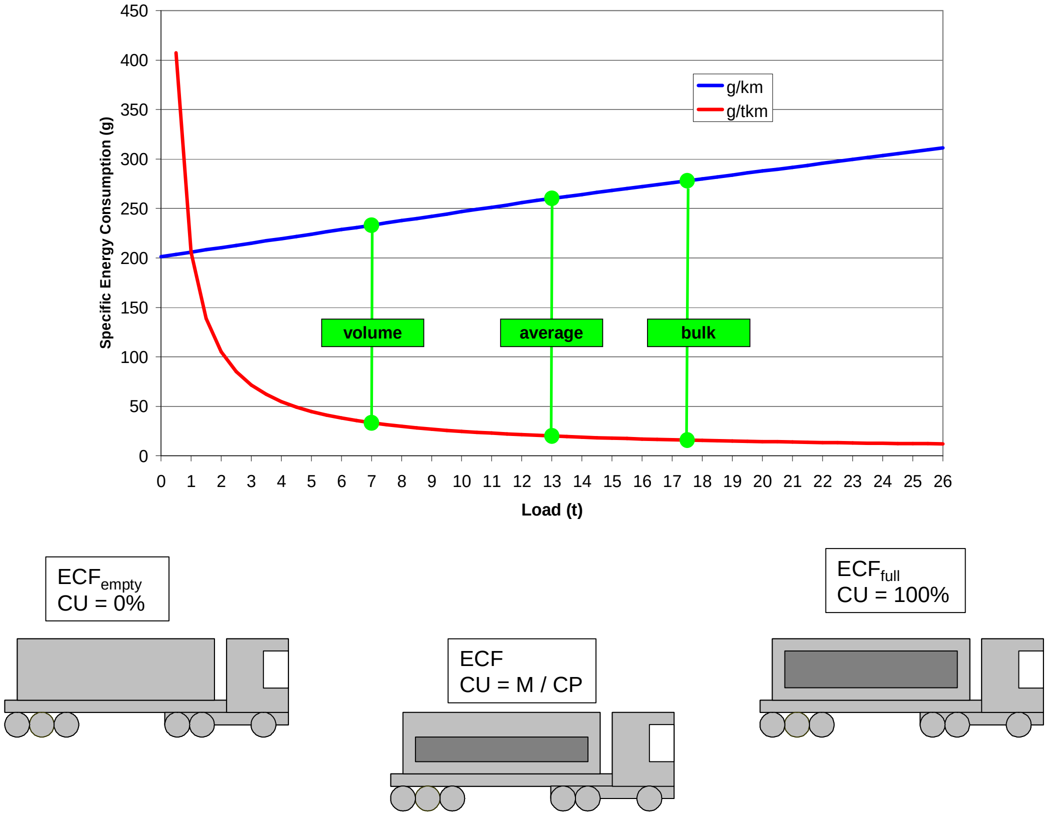
5.1.3 Final energy consumption and vehicle emissions per net tonne km

For road transport with trucks the general calculation rules described in chapter 3.3 also apply. 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 9 Energy consumption for heavy duty trucks (40 t vehicle gross weight, Euro-III, motorway, hilly) as a function of load weight



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

Definitions:

ECF	Final energy consumption with actual load (g/km)
ECF$_{empty}$	Final energy consumption without load (g/km)
ECF$_{full}$	Final energy consumption with full load (g/km)
M	Mass of freight (t)
CP	Payload capacity (t)
CU	Capacity utilisation (weight load / load capacity)

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

Source: Handbook emission factors (INFRAS 2010)

For the calculation of energy consumption and emissions per net tonne km the basic calculation rules are applied (see chapter 3.3).

The following table shows one set of final energy and vehicle emission factors per net tonne km.

Table 22 Energy and emission factors for articulated trucks >24-40 t in Europe, Euro 3, motorway, average gradient for hilly countries)

Component	Unit	Bulk	Average	Volume
Final energy consumption.	MJ/tkm	0.90	1.07	1.76
CO2	g/tkm	59	70	116
CO2e	g/tkm	61	73	120
NOx	mg/tkm	456	537	887
PM	mg/tkm	13	16	28
NMVOC	mg/tkm	42	51	89
SO2	mg/tkm	73	86	142

5.2 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.

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 EcoTransIT World must cover a wide range in regards to train weight.

5.2.1 Final energy consumption

In EcoTransIT World, energy functions are used which are verified by average values from different European railways. To take into account the different topologies of the European countries, three types of functions are used, which shall represent a “flat” (Denmark, Netherlands, Sweden), “mountain” (Austria, Switzerland) or “hilly” topology (all other countries). For EcoTransIT World 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:

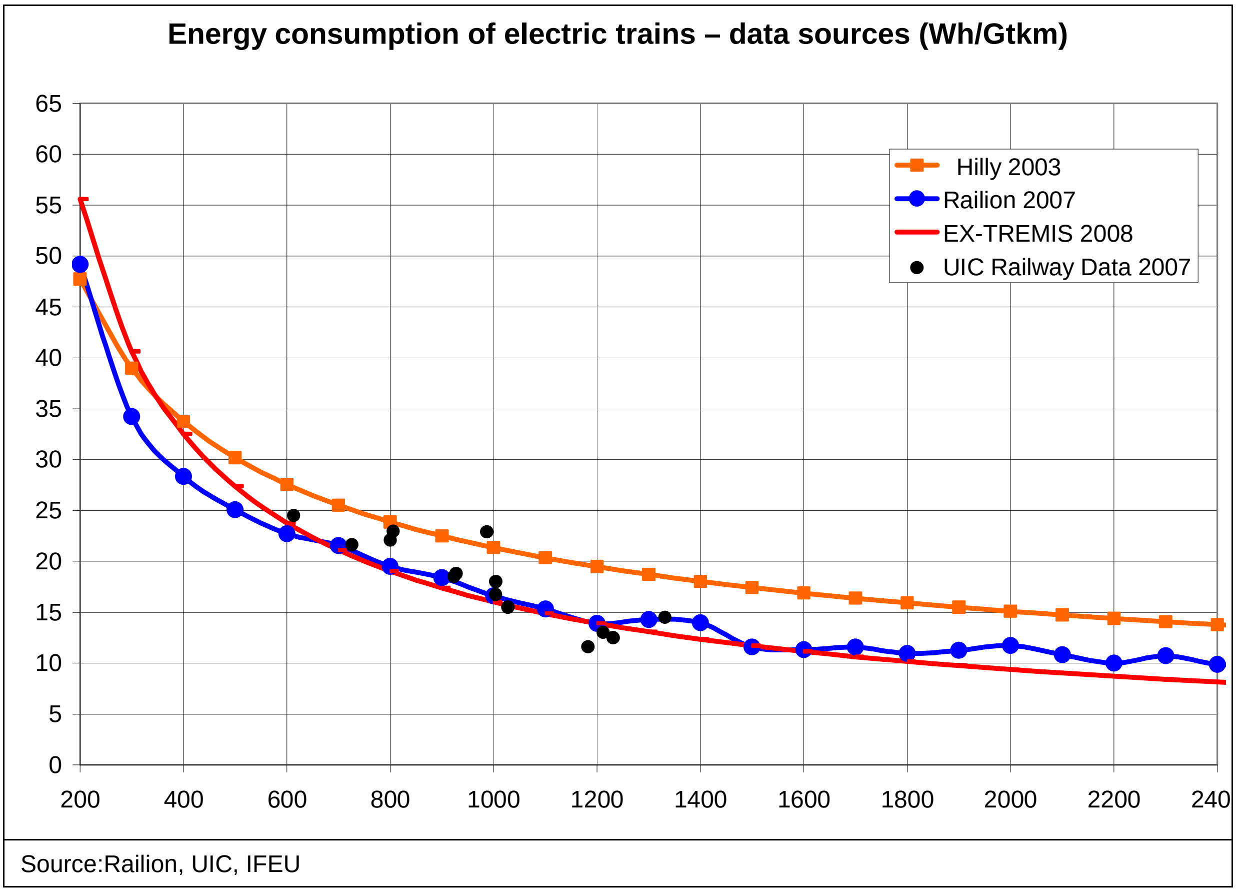
- Average annual consumption of typical freight transport by different companies, e.g. data from UIC energy statistics (last update 2007) /UIC 2009/
- Analysis of energy consumption of more than 200’000 rides of freight trains by Railion in 2007 in different production types and train weight classes /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 is 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 onnes) /IFEU 2008/.
- US Track1: statistics about annual energy consumption of freight trains; in 2006 the average energy consumption of diesel freight trains is 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, propose 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 vaules 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 10 Energy consumption of electric trains – data sources



A new function is generated for EcoTransIT World which includes the following assumptions:

- Train weight 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 is figured:

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

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

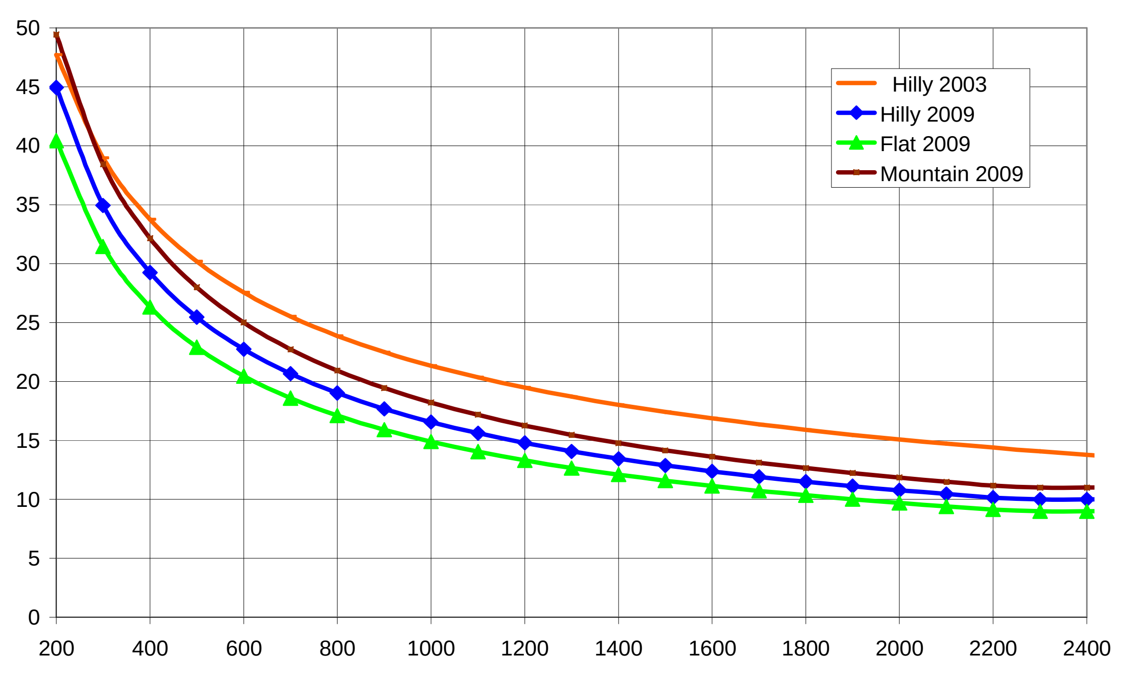
- Below 600 gross tonnes the diffusion of the values is higher. This means a higher uncertainty of the values. We propose to use the same function as for the middle weight trains due to define the function as simple as possible.
- Above 1500 gross tonnes the Railion values show no significant reduction 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 then keep 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 old EcoTransIT “hilly” function.

Figure 11 Functions for the energy consumption of electric trains

Energy consumption of electric trains – Functions in EcoTransIT World (Wh/Gtkm)



Source: EPS, Raillion, TRT, UIC, USDOT, IFEU

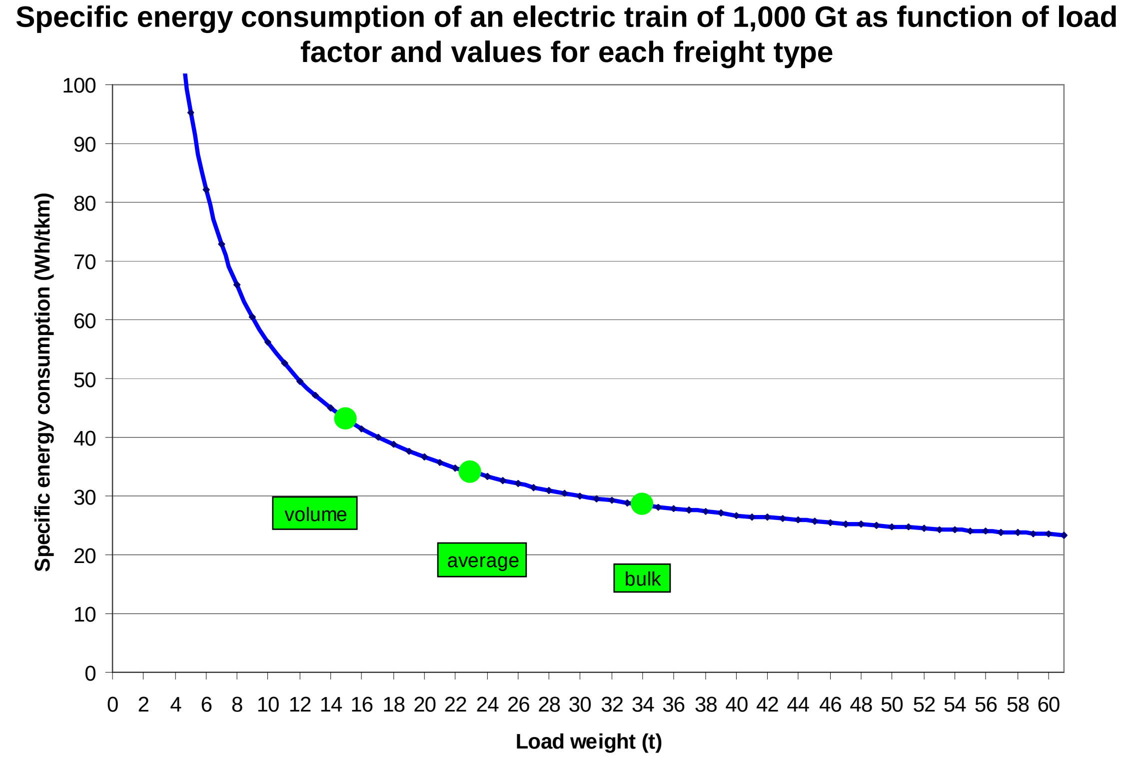
The specific energy consumption per net tonne km is calculated for each train type with the following formula:

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

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

The following figure shows the specific energy consumption as a function of the net tonnes/gross tonne relation for a 1’000 tonne electric train and the values for each freight type.

Figure 12 Specific energy consumption of an electric train of 1’000 Gt as function of load factor and values for each freight type



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

Source: EPS, Raillion, TRT, UIC, USDOT, IFEU

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

Table 23 Specific final energy consumption for selected electric trains

Train Type	Final Energy Consumption			
	Train	Freight		
		Bulk	Average	Volume
Unit	Wh/Gtkm	Wh/Ntkm		
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

Source: Railion 2007, IFEU 2008

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 electro 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 electro 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 5.6.1, Figure 21.).

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 an 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 24 Specific final energy consumption for diesel trains

Train Type	**Final Energy Consumption**			
	Train	**Freight**		
		Bulk	**Average**	**Volume**
Unit	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
Values of heay trains	**Average (not specified)**			
China 2008	27			
Canada 2003	33	61		
US Track 1 2006		66		
Source: Railion 2007, IFEU 2008, EPS 2005, USDOT 2008				

5.2.2 Emission factors for diesel train operation

Different from electro traction, emissions for diesel traction are also produced during the operation of the vehicle. These emission factors are stated as specific values based on the fuel consumption (in g/kg diesel fuel). Values have been made available by several European railway companies /Railway companies 2002/, the UIC Raildiesel study /UIC 2005/ and from Canada /EPS 2005/. Table 11 summarises the emission factors for diesel trains of different railway companies. EcoTransIT World uses the new values of DB 2008 for all railways.

Table 25 Emission factors for diesel trains (NOx, NMHC, PM)

	Unit	NOx	NMHC	PM
Different European Railway Companies, 2001	g/kg	40-70	1.8-5.7	0.6-5.0
UIC Rail Diesel, main locomotives (2005)	g/kg	64.7		1.15
DB 2008	g/kg	48.3	4.63 (HC)	1.35
Canada 2003	g/kg	63.9	2.8 (HC)	1.4
Default EcoTransIT World 2010	**g/kg** **kg/TJ**	**48.3** **1,126**	**4.63** **106**	**1.3** **31**
Source:UIC 2005, DB 2008, EPS 2005, Railway Companies 2002				

Sulphur dioxide emissions depend on sulphur content on fuel. These values are country specific. The sulphur content of diesel fuel is assumed according the valid legislation. In EcoTransIT Word for railways the same values as for road transport are used (see Chapter 5.1, Table 21).

For greenhouse gases the following fuel based emission factors are applied:

Table 26: Emission factors for diesel trains (greenhouse gases)

	g/kg	kg/TJ
Carbon dioxide (CO_2) – conventional diesel fuel	3,179	74,000
Carbon dioxide (CO_2) – biodiesel	0	0
Laughing gas (N_2O)	0.043	1.0
Methane (CH_4)	0.086	2.0
Carbon dioxide equivalent (CO_2e) - conventional diesel fuel	3'268	74'348
Carbon dioxide equivalent (CO_2e) - biodiesel	15.3	348
Sources: UBA, IFEU		

5.3 Sea transport

5.3.1 Calculation of Marine Vessel Emission Factors

Sea-transport emission factors have been developed for EcoTransit World different than those for other modes, because of the lack of sufficient literature data on those factors. While /Buhaug 2008/ has published CO_2 efficiency figures for a variety of ocean going vessels, it lacks emission factors for other pollutants. Therefore it was decided to re-work the approach taken by IMO /2009/ and Buhaug /2008/ with the parallel derivation of other pollutant emission factors.

The derivation of emission factors for ships used for the EcoTransIT World model is based on a bottom-up approach. A bottom-up approach for marine vessels is based on activity and technical data and offers a reliable methodology for estimating emissions from individual ships as well as groups of ships, ship types and emissions in specific geographies. IMO /2009/ has estimated the global maritime emissions using a bottom-up approach. ”The international team of scientists behind (the IMO) study concluded that the activity-based estimate is a more correct representation of the total emissions from the world fleet (…) than what is obtained from fuel statistics.” /Buhaug et al. 2009, p. 9/ Activity based bottom-up modelling has also been used in various emission inventory studies of port and coastal areas around the world. Scientific assumptions and default technical data were verified through real time monitoring for the inventories of the Ports of Los Angeles and Long Beach /Corbett 2004/ although empirical data is generally scarce.

The expansion of the model to include carrier specific emission figures is principally possible. Most container carriers report their emission performance in g/TEU-km, which is compatible with the EcoTransIT World methodology (see for example the Clean Cargo Working Group).

5.3.2 Principle activity-based modelling structure

In EcoTransIT World, underlying emission factors are developed for different vessel types. The vessel types that are differentiated are:

- General Cargo Vessels
- Dry Bulk Carriers
- Liquid Bulk Carriers
- Container Carriers
- Roll-on-Roll-off vessels (in ferry services)

Other vessels are not included in the first version of EcoTransIT World because of their differing cargo specifications and lower relevance for the likely EcoTransIT World user. Those vessel types include LNG and LPG gas carriers as well as car carriers. Also not included are non-cargo vessels such as cruise ships, although the same methodology could principally be applied. Ferries and RoRo vessels 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 for land transport. The vessels type specification follows the Lloyds Maritime Intelligence Unit (LMIU) coded vessel categories (Table 27).

Table 27: Considered vessel types in EcoTransIT World. Source Lloyds Marine Intelligent Unit (MIU)

LMIU Code	Vessel Type	Vessel Sub-types included
A 12	Tanker	Chemical, chemical/oil products tanker
A 13	Tanker	Oil, crude oil tanker
A 14	Tanker	Other liquids
A 21	Bulk Carrier	Bulk dry
A 22	Bulk Carrier	Bulk dry/oil
A 23	Bulk Carrier	Self-discharging bulk, LoLo bulk dry cargo, LoLo general dry cargo
A 24	Bulk Carrier	Other dry bulk, wood chips, forest products,
A 30	General Cargo Carrier	Heavy load
A 31	General Cargo Carrier	General cargo, cargo ship, icebreaker
A 32	General Cargo Carrier	Passenger/general cargo
A 33	Container Carrier	Container, container/fixed guides
A 34	Refrigerated Vessel	Refrigerated cargo, fully refrigerated ships
A 35	RoRo	RoRo cargo
A 38	General Cargo Carrier	Other dry cargo

Not considered in this version of EcoTransIT World:

LMIU Code	Vessel Type	Vessel Sub-types included
A 11	Tanker	Liquefied gas, LNG carriers, LPG carriers
A 35	Passenger	Passenger/RoRo cargo, car carriers, vehicle carriers, ferries[2]
A 37	Passenger	Passenger vessels, cruise ships

The modelling of emission factors is based on technical data of 4616 sample vessels. Technical data was collected from Lloyds Register of Shipping /Lloyds 2009/. The validity of the sample was tested by comparing the findings with the aggregate results for CO_2 emissions in the updated greenhouse gas study by the IMO /Buhaug et al. 2008, IMO 2009/.

Emission factors are developed for each individual vessel (EFv). The principle derivation of emission factors uses main and auxiliary engine data, capacity data and activity data. Emission factors for container vessels have been derived in g/TEU-km (TEU = twenty foot equivalent unit = standard container of 20' length), whereas for all others vessels the factors are based on g/tonne-km. The EFv are based first on nominal carrying capacity with the subsequent inclusion of vessel utilization and empty trips.

EFv = engine data x vessel capacity data x vessel activity data x vessel utilization factor

The final emission factors for the different vessel types, size classes and trade lanes are then weighted averages of the vessels' individual emission factors. In the expert modus, specific vessel types and size classes can be selected. In the default modus of EcoTransIT

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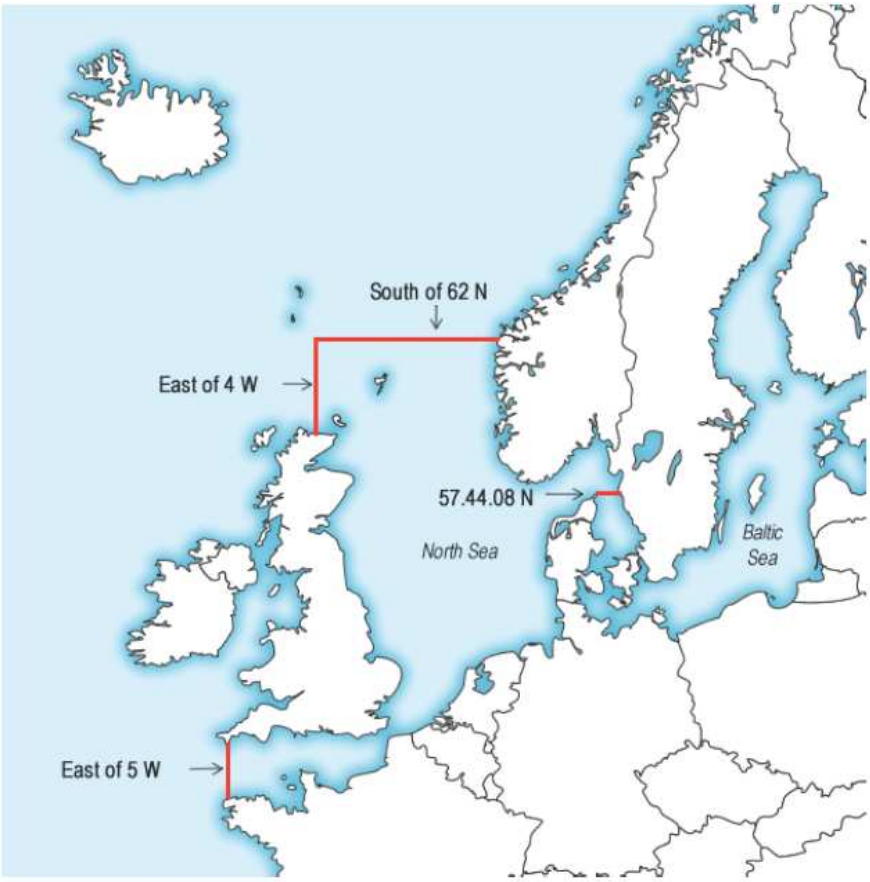
[2] For ferries see section under road and rail transport.

World, vessel types and size classes have been grouped to derive trade lane specific emission factors. The appropriate vessel emission factor is automatically selected when selecting the type of cargo and the port pairs in the model. For example, “dry” and “liquid” bulk cargo selection from North America to Europe results in the calculation with an aggregate transatlantic bulk carrier, whereas “containerized” results in the selection of container carriers. Three types of default transport loads exist within containerized transport: volume good, average weight and heavy weight cargo. Average weight cargo is the default assumption. Bulk carriers are always calculated as carrying heavy weight cargo.

Figure 13: Demarcation of the North and Baltic Sea SECAs. /Sustainable Shipping 2009/



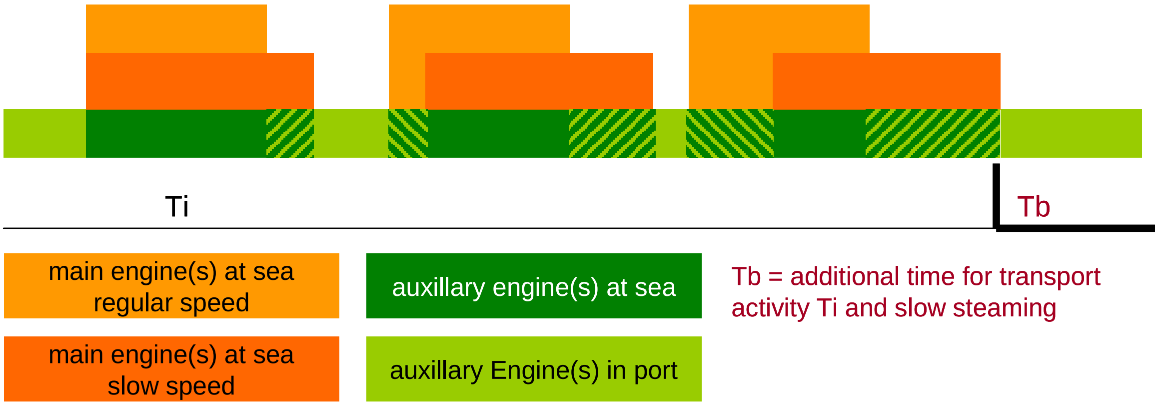
In addition to the distinction above, separate emission factors have been developed for the Sulphur Emission Control Areas (SECAs) North Sea and Baltic Sea. A vessel route with ports in those sea areas results automatically in reduced sulphur oxides and particulate matter emissions. Emissions of vessels travelling beyond the SECA will present a combination of SECA and non-SECA emissions, assuming that they switch to higher-S bunker fuels outside the SECA area.

For each region different sulphur levels in fuel apply. Generally the global average sulphur level is assumed to be 2.37 % in heavy fuel oil /MEPC 2009b/. For auxiliary engines, lower sulphur levels were assumed because of the partial use of marine diesel oil and marine gas oil for those engines. Furthermore, for the in-port and Sulphur Emission Control Areas different sulphur levels were assumed.

Sea-Region	Engine-type	S general [%]	S in SECA [%]
General open sea and in port	Main engine HFO	2.37	1.0
General open sea and in port	Main engine MDO/MGO	1.5	1.0
General open sea	Auxiliary engine	1.5	1.0
In port	Auxiliary engine	0.5	0.1
Sources: MEPC 2009b; AKN 2009			

Individual vessel emission factors are derived by calculating emissions for the main and the auxiliary engine separately and split the emissions in “main engine at sea”, “auxiliary engines at sea” and “auxiliary engines in port”. The reason for this separation is a) a differentiation of technical data, b) a differentiation of activity data and c) the desire to allowing users to model speed reductions of vessels. First, main and auxiliary engines have different engine load patterns at sea and in port. Second, depending on the vessel type and trade lane the split between at sea and in port differs. And third, a vessel speed reduction only results in reduced emissions from main engines at sea, whereas the emissions of auxiliary engines at sea increase due to the longer duration of the trip and the emissions in port remain unchanged while delivering the same transport services. In order to model the effects of reduced vessel speeds, each vessel is modelled for a virtual year period in the standard assumption. The emissions, both from main and auxiliary engines, are then normalized to one tonne kilometre, including the emissions from auxiliary engines in port. If reduced vessel speeds are modelled, the vessel’s activity extends the one year period in order to deliver the same transport services. However, emissions are again normalized to transporting one tonne kilometre.

Figure 14: Schematic effects of fuel consumed and greenhouse gas emissions with slow steaming.



Another split is made between fuel based and engine based pollutants. Fuel based pollutants are emitted in a close correlation to the amount of fuel burned. Engine based pollutants are emitted according to the physical-chemical characteristics of the engine technology.

Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and sulphur oxides (SOx) are mainly fuel based emissions. Due to newly developed emission factors for nitrogen oxides (NOx) that take the new NOx limits into account /IMO 2009/ NOx is considered a fuel based factor as well, although technically it is more determined by engine technologies. Bases for calculating those is the fuel consumption per tonne-km. Carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) are mainly engine-based emissions. CO, HC and PM are calculated based on the engines' power demand for transporting one tonne-km. Particulate matter emissions are both, fuel and engine based. Large parts of marine particulate emissions stem from the sulphur content in marine fuels. However, the combustion efficiency also influences particulate matter emissions, in particular the soot and black carbon fraction. Recent studies have found not only a weak correlation between the fuel sulphur and the PM emissions but also between engine power and PM emissions /CARB 2007/. For this study a formula that derives PM emission factors in g/kW-h, taking the fuel sulphur content into account was used /CARB 2007/.

5.3.3 Development of class and trade-lane specific emission factors

The EcoTransIT World model has two modes, a standard mode and an expert mode. Emissions have been grouped for the standard mode according to vessel types, sizes and major trade lanes. Page 53 lists the vessel types and trade-lanes that are differentiated in the EcoTransIT World model. Table 28 lists all port-region pairs and defines the trade-lanes.

The distinctive vessel groupings per trade lane are based on sample analysis of transport services of ocean carriers[3]. Size differentiation can be particularly found in container trade, whereas bulk transport depends more on the type of cargo and distance sailed.

The major container trades are distinctive in terms of volumes, goods and 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 usually with a broader range of vessels above 3 000 TEUs. In both trade lines also ultra-large container vessels are deployed. In the Europe – North America trade the bulk numbers of container vessels are between 2 000 and 6 000 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 an average “international” emission factor was formed and several intra-continental emission factors were developed (Table 28). A similar approach was used for bulk vessels. However, the distinction here is based on certain size restrictions in particular regions.

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[3] The following carrier schedules were analyzed to develop the vessel size groupings per major trade lane: Container carriers: NYK Line, OOCL, Hyundai Merchant Marine, APL, CMA-CGM, and Hapag Lloyd; for bulk carriers: Seabulk, Polar, AHL Shipping Company.

Table 28: List of world trade lanes. EU = Europe, NA = North America, LA = Latin America, ME = Middle East, As = Asia, Oz = Australia and Pacific Islands

From / To	EU - Europe	NA - North Am.	LA - Latin Am.	AF - Africa	ME - Middle Ea.	AS - Asia	OZ - Ozea-nia
EU - Europe	InterEU	EUNA	EULA	EUAF	EUME	EUAS	EUOZ
NA - North Am.	EUNA	InterAm	NALA	International	NAME	NAAS	International
LA - Latin Am.	EULA	NALA	InterAm	International	LAME	LAAS	International
AF - Africa	EUAf	International	International	InterAf	International	International	International
ME - Middle Ea.	EUME	NAME	LAME	International	International	MEAS	International
AS - Asia	EUAs	NAAS	LAAS	International	MEAS	InterAs	InterAs
OZ - Ozeania	EUOz	International	International	International	International	InterAs	International

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. The Suez Canal does not pose a restriction to even the largest container ships. However, bulk carriers are limited to approximately 200 000 dead weight tonnage[4] (DWT). The Panama Canal poses both restrictions for bulk carriers (ca. 80 000 DWT) and container ships (ca. 4 300 TEU with some vessels up to 5 000 TEU capacity). The Baltic Sea entrance is limited to bulk vessels of maximum 120 000 DWT in general. However, the ports in the Baltic are mostly served by smaller feeder vessels.[5] Furthermore, the Baltic Sea as well as the North Sea are so called Sulphur Emission Control Areas with limits on fuel sulphur at sea and in port /Sustainable Shipping 2009/. Thus a separate EU SECA trade lane was formed. The limitations are due to limits in the vessels draft, as well as length and width if locks are in place. The Panama Canal is currently under construction and will be expanded to accommodate larger vessels.

All trade-lane specific emission factors are weighted averages derived from the individual sample vessels emission factors. The vessel emission factors are weighted according to the transport work of the vessels as a combination of cargo capacity and average utilization. Table 29 shows the trade-lane and vessel type specific emission factors in the default mode of EcoTransIT World. The default mode does not differentiate between liquid and dry bulk.

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[4] 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. 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/

[5] Personal communication Port of Oslo.

Table 29: Default vessel categories depending on cargo type and trade lane.

Vessel types	Trade and Vesselcategory names	Aggregated size class	Trade Lane					
BC (liquid, dry, and General Cargo)	Suez trade	Aframax / Suezmax	EUAS	EUME	EUAS	NAME	LAME	MEAS
BC (liquid, dry, and General Cargo)	Transatlantic trade	Handymax / Panamax	EUNA					
BC (liquid, dry, and General Cargo)	Transpacific trade	Handymax / Panamax / Aframax / Suezmax	NAAS					
BC (liquid, dry, and General Cargo)	Panama trade	Handymax / Panamax	NALA					
BC (liquid, dry, and General Cargo)	Other global trade	Handysize / Handymax / Panamax / Aframax	International	EULA	EUAF	EUOZ	LAAS	
BC (liquid, dry, and General Cargo)	Intra-continental trade	Feeder / Handysize / Handymax	InterEU	InterAs	InterAm	InterAf		
CC	Suez trade	4700 - 7000 (+) TEU	EUAS	EUME	EUAS	NAME	LAME	MEAS
CC	Transatlantic trade	2000 - 4700 TEU	EUNA					
CC	Transpacific trade	1000 - 7000 (+) TEU	NAAS					
CC	Panama trade	2000 - 4700 TEU	NALA					
CC	Other global trade	1000 - 4700 TEU	International	EULA	EUAF	EUOZ	LAAS	
CC	Intra-continental trade non EU	1000 - 3500 TEU	InterAs	InterAm	InterAf			
CC	Intra-continental trade EU	500 - 2000 TEU	InterEU					
CC	EU SECA trade	500 - 2000 TEU	BALTIC					
Great Lakes BC		< 30000 dwt	InterAm					
(BC = bulk carrier; CC = container vessel GC = general cargo ship)								

Table 30: Vessel types and sizes that can be selected in EcoTransIT's expert mode.

Vessel types)	Trade and Vessel category names	Aggregated size class
GC	Coastal	< 5000 dwt
GC	EU SECA Coastal	< 5000 dwt
BC / GC (dry)	Feeder	5000 - 15000 dwt
BC / GC (dry)	Handysize	15000 - 35000 dwt
BC (dry)	Handymax	35000 - 60000 dwt
BC (dry)	Panamax	60000 - 80000 dwt
BC (dry)	Aframax	80000 - 120000 dwt
BC (dry)	Suezmax	120000 - 200000 dwt
BC (liquid)	Feeder	5000 - 15000 dwt
BC (liquid)	Handysize	15000 - 35000 dwt
BC (liquid)	Handymax	35000 - 60000 dwt
BC (liquid)	Panamax	60000 - 80000 dwt
BC (liquid)	Aframax	80000 - 120000 dwt
BC (liquid)	Suezmax	120000 - 200000 dwt
BC (liquid)	VLCC (+)	> 200000 dwt
CC	Feeder	<1000 TEU
CC	EU SECA Feeder	500 - 1000 TEU
CC	like Handysize	1000 - 2000 TEU
CC	EU SECA like Handysize	1000 - 2000 TEU
CC	like Handymax	2000 - 3500 TEU
CC	like Panamax	3500 - 4700 TEU
CC	like Aframax	4700 - 7000 TEU
CC	like Suezmax	>7000 TEU
Global average CC	World	over all ships
(BC = bulk carrier; CC = container vessel GC = general cargo ship		

5.3.3.1 Sources of basic emission factors for marine vessels

Main engines

Since differentiated emission factors for vessels-classes can not be found in literature or statistical data bases such as TREMOVE, they had to be developed for EcoTransIT World using a bottom-up methodology. The bottom-up methodology has been refined in the context of marine vessel emission inventories /Aldrete et al. 2005/, /Anderson et al. 2003, 2004/, /CARB 2007/, /Corbett and Fischbeck 1997/, /Corbett and Köhler 2002/, /Corbett 2004/, /ENTEC 2002/, /EPA 2009/, and for estimating global greenhouse gas emissions from ships /Buhaug et al. 2008/, /IMO 2000, 2009/.

Emissions of carbon dioxide depend on the carbon content of marine fuels. While there have been differences in past inventories in regard to the assessment of the carbon content and the resulting emissions, they have beenminimal. EcoTransIT World utilizes the CO_2 emission factors from marine bunker fuels published in IMO's guidelines for the Energy Efficiency Operational Indicator (MEPC 2009). Methan and Nitrous oxide are the other two parameters considered to derive CO_2 equivalent emissions. Their contribution is small, although a high degree of uncertainties exist. Emission factors by the IPCC /2006/ are used.

Table 31: Marine fuels, main engine emission factors and sources for CO_2, CO_2 equivalent and nitrogen oxide emissions. Sources: MEPC /2005/, IMO /2009/, IPCC /2006/

For emissions of CO_2 / CO_2 eq & NOx	Source:	Emission factors [g/kg fuel]
CO_2 / HFO	IMO 2005: MEPC Circ. 471.	3.1144
CO_2 / LFO	IMO 2005: MEPC Circ. 471.	3.15104
CO_2 / MDO&MGO	IMO 2005: MEPC Circ. 471.	3.206
CH_4	IPCC Guidelines 2006	0.2828
N_2O	IPCC Guidelines 2006	0.0808
GWP factor for CH_4	IPCC 4th Assessment Report	25
GWP factor for N_2O	IPCC 4th Assessment Report	298
NOx SSD Tier (0)	IMO 2009	89.5
NOx SSD Tier (1)	IMO 2009	78.2
NOx MSD Tier (0)	IMO 2009	59.6
NOx MSD Tier (1)	IMO 2009	51.4

Sulphur oxide emissions are calculated based on the sulphur content in marine fuels. The mass of sulphur in marine fuels is expressed in mass %. It is assumed that 97.7 % of the fuel S is oxidized during combustion /EPA 2009/. The corresponding sulphur oxide emissions are derived by multiplying the mass with the factor of 2 (S + 2x mass weight of O).

Nitrogen oxide emissions are mainly engine related. Until the year 2000, marine engines were unregulated. In 1997, revisions to the Annex VI of the International Convention on the Prevention of Pollution from Ships Tier I standards for marine engines were adopted that became effective in January 2000. The standard manifested the status quo at that time and was tightened further in 2008 by adopting Tier II and Tier III standards. Tier II emission standards are effective for any new engine or major overhaul from 2011 and will also be able to adhere to by adjusting common diesel engines to those standards. The Tier II NOx adjustment may come with a slight fuel penalty /MAN 2006/, because leaner burning processes for lower NOx means less optimal combustion processes with higher fuel consumption and higher particulate matter emissions. Tier III standards, which come into effect for Emission Control Areas in 2016, may only be achieved through the application of additional exhaust gas cleaning. For NOx emission the emission factors by IMO /2009/ were used, which differentiate between Tier I and Tier II (pre 2000 and after) as well as between slow speed and medium speed engines. The factors reflect the IMO's NOx code formula /MEPC 2008/. However, because the exact engine returns per minute were not known, the IMO /2009/ were applied (Table 31).

Particulate matter emissions are important for local air quality. However, to date uncertainties of the extent of particulate matter emissions and emission factors are quite large. Particles from marine engines are dependent on the efficiency of the combustion process and also on the amount of sulphur in marine fuels. Approximately 10 % of the fuel sulphur is oxidized to Sulfate (SO_4), which directly contributes to the fine particles in the exhaust and dominates the particulate matter emissions /Janhäll 2007/. However, a recent compilation of research has found only weak correlations between the fuel sulphur levels and the particulate matter emissions of ships /CARB 2007/. The findings further reflect more the difficulties to measure particulate matter emissions and the limited number of empirical data than that it can be taken as evidence that no strong correlation exist. In order to derive the emission factors the formula developed by CARB /2007/ was used. Table 32 provides the emission factor at the fuel sulphur levels used in EcoTransIT World.

Table 32: Particulate matter emission factors for main and auxiliary engines. Source: CARB /2007/

ARB 2007 Formel: y = 46.53x + 0,25	S-content 2.70% [g/kWh]	S-content 2.37% [g/kWh]	S-content 1.50% [g/kWh]	S-content 1.00% [g/kWh]	S-content 0.50% [g/kWh]	S-content 0.10% [g/kWh]
PM 10	1.51	1.35	0.95	0.72	0.48	0.30
PM 2.5 (90% of PM10)	1.36	1.22	0.85	0.64	0.43	0.27
Source: ARB 2007, Janhäll 2007						

Main engine emission factors for carbon monoxide and hydrocarbons were taken from EPA /2009/. With its guidance on developing emission inventories of port areas, EPA had compiled a comprehensive list of factors and published valuable average emission and activity figures for main and auxiliary engines. The emission figures for main engines are differentiated for slow speed marine diesel (SSD) engines using heavy fuel oil (HFO), medium speed marine diesel (MSD) engine using marine diesel oil (MDO) and steam turbines (ST). The emission factors for the SSD and MSD engines were used in EcoTransIT World accordingly. Steam turbine powered vessels are ignored because of their small number (Table 33).

Table 33: CO and HC emission factors of the main engine. Source: EPA /2009/

	SSD HFO [g/kWh]	MSD/SSD MDO/MGO [g/kWh]
CO	1.40	1.10
HC	0.60	0.50
Source: EPA 2009; SSD = slow speed diesel; MSD = medium speed diesel; HFO = heavy fuel oil; MDO = marine diesel oil; MGO = marine gas oil		

Auxiliary engines

For auxiliary engines the assumptions were also taken from Buhaug et al. /2008/ and EPA /2009/. Depending on the auxiliary engine power, a fuel consumption of either 230 g/kWh for engines with less than 800 kW or 220 g/kWh for engines with 800 kW and more was used /Buhaug et al. 2008/. For the emissions at sea it was assumed that the auxiliary engines are fuelled with the same type of marine fuels than the main engines. In port it is assumed that auxiliary engines are fuelled with low-S marine diesel oils of 1.5 % generally and 0.1 % S in European ports due to EU regulations. Thus CO_2 equivalent emissions and sulphur oxide emissions were calculated accordingly. For NOx, CO and HC emission factors were taken from EPA /2009/.

Table 34: CO and HC emission factors for auxiliary engines. Source: EPA /2009/

Pollutants	MSD HFO 2,7% S [g/kWh]	MSD MDO 1,0% S [g/kWh]	MSD MGO 0,5% S [g/kWh]	MSD MGO 0.,1% S [g/kWh]
NOx	14.7	13.9	13.9	13.9
CO	1.10	1.10	1.10	1.10
HC	0.40	0.40	0.40	0.40
PM 10	Like main engine			
PM 2.5 (90% of PM10)	Like main engine			
SO_2	11.98	4.24	2.12	0.42
Source: EPA 2009, Janhäll 2007				

5.3.3.2 Important assumptions for calculating marine vessel emission factors

Modelling requires other assumptions, such as days at sea (for modelling the reduced speed option), the nominal design speed (Vn), the percentage of heavy fuel oil (HFO) and the default vessel utilization factor. Table 35 lists the main assumptions used for calculating marine vessel emissions. Those assumptions are averages for the respective vessels for particular trade lanes as defined in Table 29 and for individual vessel classes that can be selected in the expert mode as defined in Table 30.

For the default mode all vessels were modelled assuming an average speed of 4 % below the nominal design speed. This corresponds to an average main engine load of 80 % from the maximum continuous rating. The vessel speed may be altered in the expert mode.

Slow speed steaming is one measure of temporarily lowering emissions[6]. The emission reduction effect is due to an over-proportional decline of the emissions compared to the service speed. Thus, while the vessel carrying capacity in a given time period diminishes, the emissions diminish even more, resulting in a net-reduction of emissions per tonne-kilometre. EcoTransIT World allows to model seaborne emissions down to minus 30 % of the speed based on the vessel's design speed. The positive benefit of speed reductions below 30 % disappears and enduring operation of marine engines at very low engine loads is not recommended by engine manufacturer without modifications to the engines. The detailed calculation alogorithms are explained in the Appendix.. Chapter 6.3.1.1 provides several example emission factors for bulk and container vessels, taking different speed reductions and net-cargo container loads into account.

Table 35: Days at sea, design speed (Vn), share of heavy fuel oil and default vessel utilization factors that are used in EcoTransIT World.

Vessel type	Trade	Size class	Days at sea	Vn km/h	% HFO	Default vessel utilization factor [%]
BC (liquid, dry, and General Cargo)	Suez trade	Aframax / Suezmax	259	27.2	100%	49%
BC (liquid, dry, and General Cargo)	Transatlantic trade	Handymax / Panamax	250	26.8	99%	55%
BC (liquid, dry, and General Cargo)	Transpacific trade	Handymax / Panamax / Aframax / Suezmax	253	27.0	100%	53%
BC (liquid, dry, and General Cargo)	Panama trade	Handymax / Panamax	250	27.0	99%	55%
BC (liquid, dry, and General Cargo)	Other global trade	Handysize / Handymax / Panamax / Aframax	250	27.0	99%	55%
BC (liquid, dry, and General Cargo)	Intra-continental trade	Feeder / Handysize / Handymax	242	26.6	98%	57%
CC	Suez trade	4700 - 7000 (+) TEU	246	46.3	100%	67%
CC	Transatlantic trade	2000 - 4700 TEU	251	41.6	100%	65%
CC	Transpacific trade	1000 - 7000 (+) TEU	253	40.3	100%	65%
CC	Panama trade	2000 - 4700 TEU	251	41.6	100%	65%
CC	Other global trade	1000 - 4700 TEU	255	38.7	100%	65%
CC	Intra-continental trade non EU	1000 - 3500 TEU	256	37.5	100%	65%
CC	Intra-continental trade EU	500 - 2000 TEU	228	34.1	100%	65%
CC	EU SECA trade	500 - 2000 TEU	228	34.1	80%	65%
Great Lakes BC		< 30000 dwt	238	26.3	96%	58%
Ferry / RoRo vessel	World	Large > 2000 lm	219	36.9	33%	70%
Ferry / RoRo vessel	World	Small < 2000 lm	180	37.4	55%	70%
Ferry / RoRo vessel	EU SECA	Large > 2000 lm	219	36.9	16%	70%
Ferry / RoRo vessel	EU SECA	Small < 2000 lm	180	37.4	30%	70%
GC	Coastal	< 5000 dwt	180	25.4	100%	60%
GC	EU SECA Coastal	< 5000 dwt	180	25.4	70%	60%
BC / GC (dry)	Feeder	5000 - 15000 dwt	244	26.4	99%	60%
BC / GC (dry)	Handysize	15000 - 35000 dwt	256	27.6	99%	56%
BC (dry)	Handymax	35000 - 60000 dwt	261	26.6	99%	55%
BC (dry)	Panamax	60000 - 80000 dwt	270	26.4	99%	55%
BC (dry)	Aframax	80000 - 120000 dwt	271	26.0	100%	55%
BC (dry)	Suezmax	120000 - 200000 dwt	279	26.9	100%	50%
BC (liquid)	Feeder	5000 - 15000 dwt	203	23.2	79%	52%
BC (liquid)	Handysize	15000 - 35000 dwt	228	26.8	100%	61%
BC (liquid)	Handymax	35000 - 60000 dwt	231	27.1	100%	59%
BC (liquid)	Panamax	60000 - 80000 dwt	196	27.3	100%	53%
BC (liquid)	Aframax	80000 - 120000 dwt	247	27.1	100%	49%
BC (liquid)	Suezmax	120000 - 200000 dwt	270	27.8	100%	48%
BC (liquid)	VLCC (+)	> 200000 dwt	274	27.8	100%	48%
CC	Feeder	<1000 TEU	180	31.7	100%	65%
CC	EU SECA Feeder	500 - 1000 TEU	180	31.7	80%	65%
CC	like Handysize	1000 - 2000 TEU	259	35.5	100%	65%
CC	EU SECA like Handysize	1000 - 2000 TEU	259	35.5	80%	65%
CC	like Handymax	2000 - 3500 TEU	251	40.1	100%	65%
CC	like Panamax	3500 - 4700 TEU	250	44.7	100%	65%
CC	like Aframax	4700 - 7000 TEU	248	46.2	100%	65%
CC	like Suezmax	>7000 TEU	242	46.7	100%	70%
Global average CC	World	over all ships	238	38.6	100%	65%

Source: Buhaug 2008, own calculation

5.3.3.3 Emissions in Sulphur Emission Control Areas

Dedicated emission factor were developed for trade within the sulphur emission control ar-

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[6] A permanent related measure would be the downsizing or re-rating of the main engine.

eas (SECA) North Sea and Baltic Sea. If in EcoTransIT World a user sets the start and end point within the boundaries of the SECA, the emission factors are chosen automatically. Furthermore, specific vessels may be picked in the expert mode (Table 30).

The vessels that are travelling in the SECA areas are assumed to operate more often on marine diesel oils. Several ports in the Baltic Sea region have instituted emission differentiated harbour dues, recommended by the Helsinki Convention /HELCOM 2007/. Thus, in traffic to those ports, additional incentive exist to reduce NOx emissions as well as SOx emissions. The technologies used to achieve lower NOx emissions are Selective Catalytic Reduction (SCR) and Direct Water Injection (DWI). SCR technology requires low-sulphur fuels and thus can best operate with MDO or MGO. Thus the share of HFO oil as fuel is reduced to 70 % for general cargo vessels and 80 % for container vessels, assuming that more general cargo vessels are on dedicated trades within the SECA region. Other emission factors that would reflect the use of advanced after treatment were not considered for EcoTransIT World, but maybe added in a future version.

5.3.4 Allocation rules for seaborne transport

As stated above, the emissions of vessels are averaged over the entire return journeys, taking the load factors and empty returns into account. Furthermore, emissions are the sum of emissions from main engines at sea, auxiliary engines at sea and auxiliary engines in port (Details see chapter 5.3). All emissions are then allocated to the freight carried as follows:

Bulk vessels are calculated on a tonne-kilometre basis. All emissions are allocated to the transported tonnes of freight.

The emissions of container vessels are calculated on a container-kilometre basis (TEU-km). All emissions are allocated to the number of containers. If the user knows the weight and type of its cargo, but not the number of containers, the weight is converted into the number of containers first. Therefore, the emissions of the container ship transport are larger if a certain tonnage of light goods is carried compared to the same tonnage of average goods. For example:

*100 t light goods in containers = 16.7 TEU = 16.7 * emission factors * distance*

*100 t average goods in containers = 9.5 TEU * emission factors * distance*

If the user chooses TEU as type of freight and knows the number of containers transported, the net-weight in containers only matters for the on- and off-carriages.

5.3.5 Allocation method and energy consumption for ferries

The modelling of ferries is tricky because all vessels are quite different from each other and because the allocation between passenger and goods transport is a controversial issue. So different allocation methodologies are proposed, e.g. by /Kristensen 2000/ or /Kusche 2000/.

For EcoTransIT World we use the allocation method which has been suggested for the calculation model of NTM by /Bäckström 2003/. This method allocates according to the number of decks on the ferry. The number of passenger and vehicle decks is considered in the first step of the allocation. It should also be taken into account if these decks are only partially used for certain vehicle categories or if they do not extend over the full length of the ship.

The second step of the allocation divides the length of lanes (lanemeters) occupied by the considered vehicles by the total length of the occupied lanes.

The following fuel related average values have been calculated according to this method for a concrete example of TT-Lines. It replaces the values of Scandlines ferry, which were used until 2008-:

Lorry (30 gross tonnes)	18 g fuel/gross-ton-km
Railcar (46 gross tonnes)	18 g fuel/gross-ton-km

These values are taken and differentiated according to vehicle types and kind of good. The resulting specific energy values are summarised in the following table.

Table 36 Specific Energy Consumption for ferries

	Final energy consumption (g fuel/Ntkm)				
	Rail	**Truck <7.5t**	**Truck 7.5-12t**	**Truck 12-24t**	**Truck 24-40t**
Bulk (heavy)	31	52	48	38	34
Average	36	60	55	43	38
Volume (light)	46	95	86	63	55
Source: Bäckström 2003, TT Lines 2009, IFEU assumptions					

These values represent a ferry example and are derived by a concrete allocation method. They indicate the order of magnitude, but may vary much for other ferries and ferry companies.

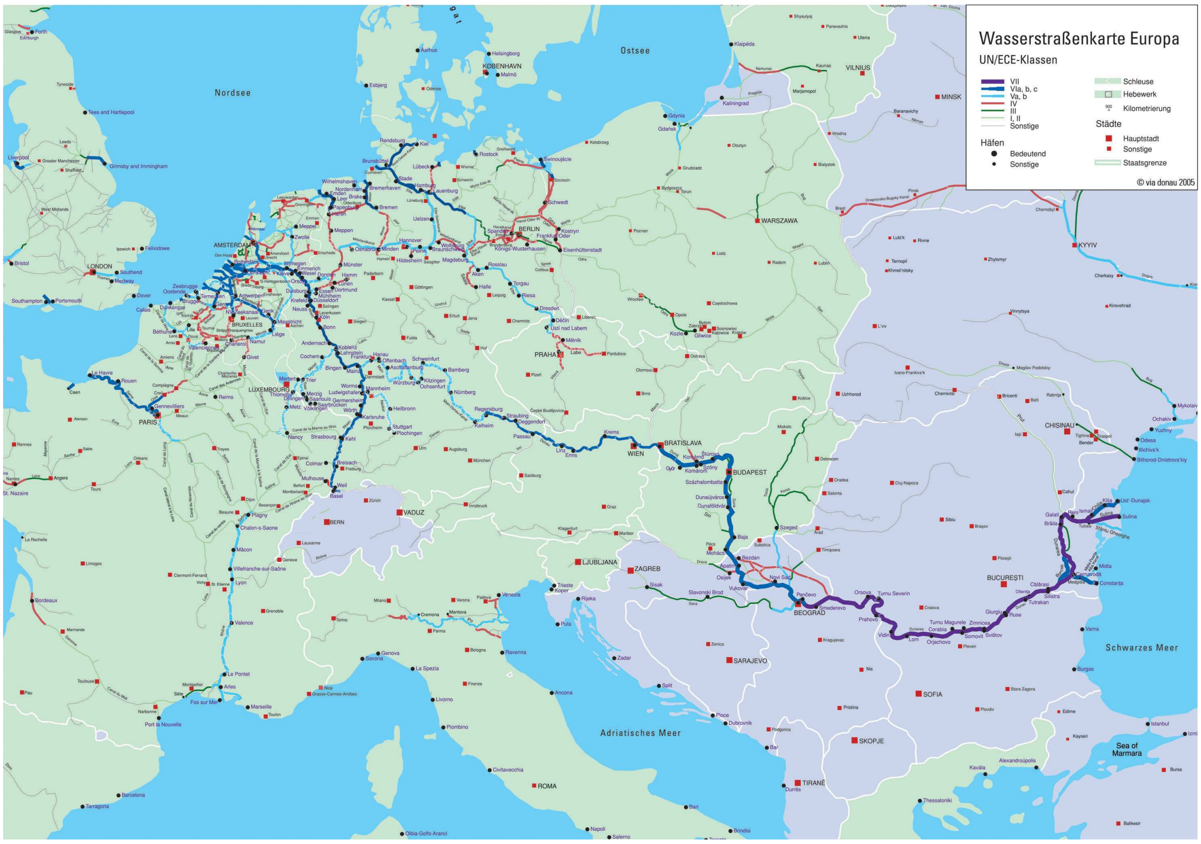
5.4 Inland waterway transport

5.4.1 General approach and assumptions for inland vessels

Inland vessels are approached similary to ocean going vessels. A bottom-up modelling based on assumptions for each vessel classes was used.

EcoTransIT World faces the challenge to cover the entire world. There are only few waterways worldwide that are considered in EcoTransIT World. The majority of waterways are in Europe. Most prominent are the rivers Danube, Elbe, Rhine, and Seine[7], which are at least in sections categorized as class VI according to the UNECE code for inland waterways /UNECE 1996/ Other rivers and canals in Europe are of class V or smaller. Figure 15 depicts the European waterways. All European waterways class IV and higher are included in EcoTransIT World.

Figure 15: European inland waterways and their classification



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

Prominent non-European waterways are the Mississippi in the United States. Worldwide approximately 50 countries have navigable waterways of more then 1 000 km length (Figure 16). However, inland freight navigation is underdeveloped in most countries /BVB 2009/ EcoTransIT World enables inland waterways calculation on the largest of the global waterways, such as the Yangtze, Ganges and Amazonas.

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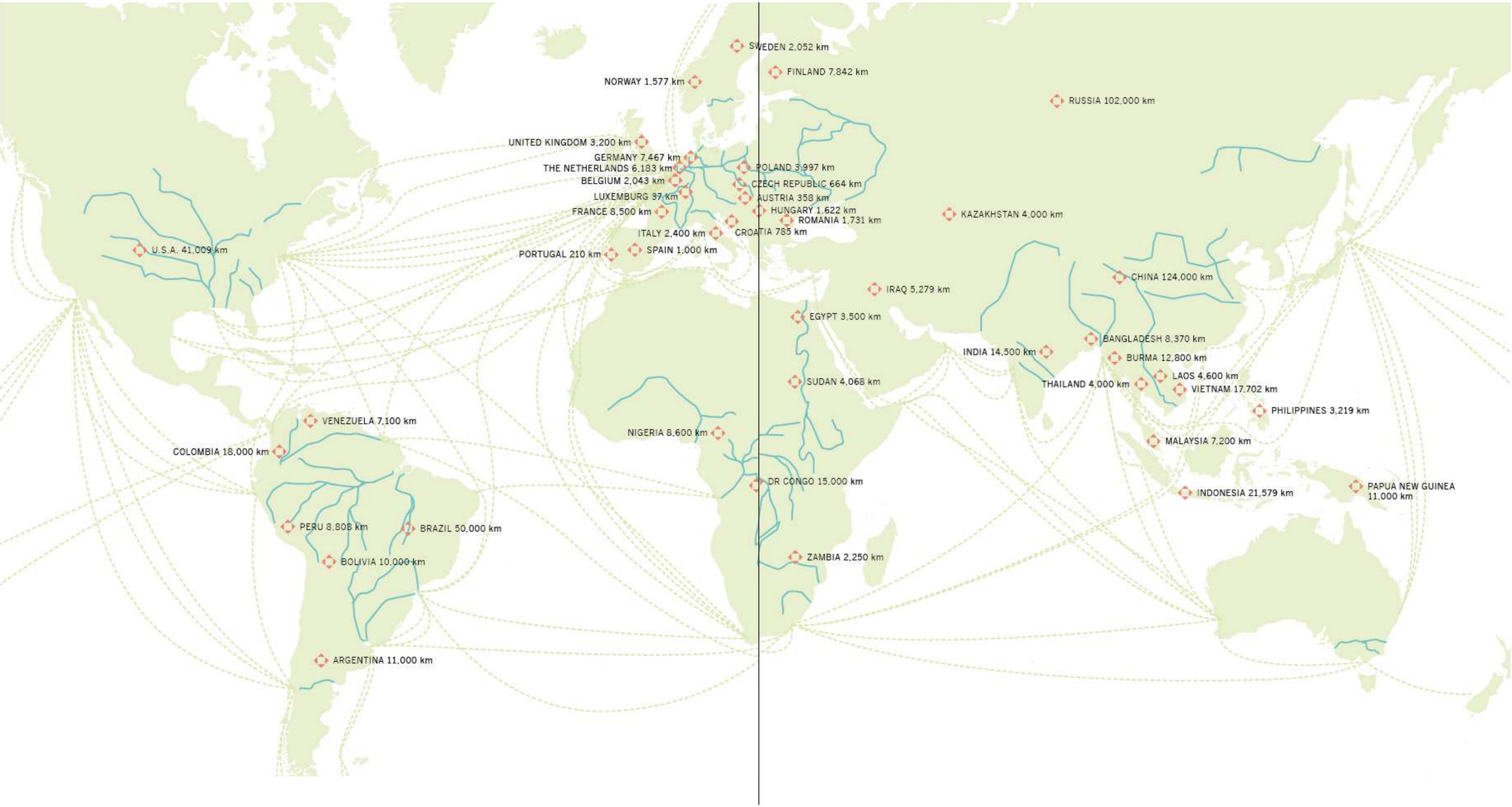

Figure 16: Worldwide inland waterways of more than 1 000 km length. Source: /BVB 2009/.

The distinction between inland waterways up to class IV and those of classes V and VI is important, because the size and carrying capacity of the inland barges significantly increases on class V and larger rivers. The maximum vessel size on a class IV river is an Europaship, whereas class V and higher waterways maybe travelled by larger push boats and vessels of the JOWI class. EcoTransIT World differentiates between two inland barges and allocates them to particular inland waterways.

Figure 17: Inland vessel configuration as motorship (Europaship-type), motorship with barge and push boat with four barges. Source: Günthner et al. 2001.

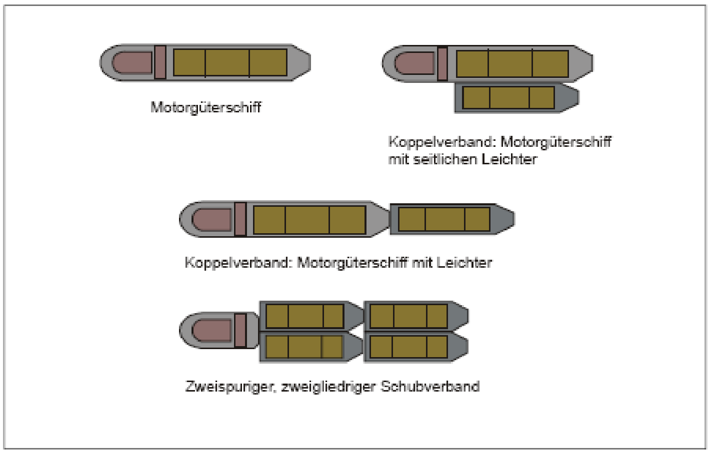

Abb. 3-2: Motorgüterschiff, Koppelverband und Schubverband

The used vessels and their characteristica are presented in Table 37. Typical vessels were used in order to model the emissions. It was further assumed that the vessels are equipped with Caterpillar (Cat) engines, which are representative, to provide some technical data. Fuel consumption was taken from engine specifications by Caterpillar and a tolerance of 5 % was added.

Table 37: Typical characteristica of inland vessels.

Vessel type	Cargo capacity [t]	TEU capacity	ME power [kW]	Aux power [kW]	Engine example	Fuel con-sumption g/kWh[8]
IV, Neo K	655	N/A	336	102	1x Cat 3408C	229
IV, Europaship	1 350	(100)	650	260	1x Cat 3508B	223
Va, RoRo, Container	2 500	200	1 140	456	1x Cat 3512	211
Va, Tankship	3 000	N/A	1 460	585	1x Cat 3516	212
VIa, JOWI ship	5 500	470 - 500	3 200	1 000	2x Cat 3516	212
VIb, Push Convoy (4 units)	7–16 000 (11 000)	1 100	4 000	1 200	3x Cat 3516	209

The two river categories (≤IV and >IV) are used in EcoTransIT World and two distinct aggregate averages are build. The aggregate emission factors were build by weighting the different vessel sizes and combining them to a vessel class IV (Europaship and Neo K) and vessel ≥IVa. It is assumed that on rivers of category V and up both Europaship vessels and larger vessels can be found. Thus the category >IV includes the Europaship-type vessels. Vessels smaller Neo K vessels are not considered in EcoTransIT World because of their minor role in freight transport.

EcoTransIT World does not take the direction of travel into account in order to treat all modes of transport similar[9]. The principle of EcoTransIT World is that differences on transport legs are averaged over the entire leg because it is assumed that the transport purchaser can not be made responsible for different performances in particular directions but has to bear responsibility for the average performance. For example differences in capacity utilization are averaged over the entire return leg. Similarly is the fuel consumed per distance travelled in flowing rivers, such as the Rhine, averaged. Different fuel consumptions per distance up- and down-river are respectively not considered. A transport purchaser takes responsibility of the average performance regardless of the direction of the transport.

5.4.2 Emission factors for inland vessels

Marine engines installed before 2002 in Europe and 2004-07 in North America are so called Tier 1 engines. To date, due to the average age of inland vessels, the emission Tier 2 standards play practically no role. In the Planco study /2007/ emission factors were averaged over vessel classes in dependence to their age profile using a regression analysis form the Tier 2 regulations. However, the resulting emission factors even for those vessels in class categories of old age are not significantly above the Tier 2 limits. Emission factors for Category 1 engines prior to regulation were used in for emissions inventory of inland water traffic in the Great Lakes

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[8] Including a +5 % tolerance.

[9] Ocean going vessels and aircrafts too have different fuel consumptions over ground depending on ocean currents and winds.

region /Lindhjem 2004/. Since off-road diesel engines in North America and Europe are essentially the same[10], those emission factors were used for EcoTransIT World. The factors differentiate between engines with less than 1 000 kW and with 1 000 kW and more. Most engines on inland vessels are between 500 and 2000 kW and fall in the emission threshold category 1 with 2.5 to 5 litre displacement.

Sulphur dioxide emissions depend on the fuel sulphur levels. In Europe those are restricted to 1 000 ppm[11] or 0.1 % for domestic marine diesel fuels. In the United States non-road diesel fuel's sulphur levels were reduced to 500 ppm in 2007 and will be further reduced to 15 ppm starting in 2010. Fuel consumption is estimated between 200 g/kWh /Planco 2007/ and 210 g/kWh (Lindhjem 2004). Own research based on manufacturer data by Caterpillar and Cummins indicate that fuel consumption is approximately 210 g/kWh for engines >1 000 kW and 220 g/kWh for engines $\leq$ 1 000 kW /Caterpillar 2006/.

Push boats and tug boats are the dominant inland vessels in North America /Lindhjem 2004/, except for deep draft vessels that provide the link service between Great Lakes destinations and the deep sea port in Montreal. Vessels in US domestic traffic are listed in a data base by the US Army Corps of Engineers /USACE 2009/. An analysis revealed that 90 % of the push boats have less than 3 200 kW. 50 % of the push boats have less than 760 kW. Thus, the US inland vessels are principally of the same size as their counterparts in Europe. The only difference is lower fuel sulphur contents of 15 ppm or 0.0015 %.

Table 38: Basic emission factors for inland vessels used for EcoTranist World. Source Lindhjem 2004

	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	SOx [g/kWh]	PM [g/kWh]
< 1 000 kW	1.5	0.27	10.0	0.6 – 4	0.3
$\geq$ 1 000 kW	2.5	0.27	12.99	0.6 – 4	0.3

Analog to modelling the ocean going vessels, the emission factors were calculated on the basis of individual vessels, assuming the transport work for one theoretical year. In order to build the weighted averages per aggregate class, the number of inland vessels of particular size /Planco 2007, Table 39/ was allocated to the modelling vessels. For push boats, it was assumed that a push boat with a certain power pushes a certain number of barges and thus determines in relation to its power the total transport work of the category push boat (Table 39). The theoretical carrying capacity of all German inland vessels is three times the real transported amount of cargo. Thus, it was thus assumed, that vessels are only utilized 1/3 of the year. The remainder of time they lay idle with only auxiliary engines running for half the time and receiving onshore power the other time. It was further assumed that on the empty voyages vessels would require 40 % less power due to a larger freeboard and distance to the bottom of the rivers and chan-

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[10] The off-road engine manufacturer and the off-road engine market is a global market with few large players providing the bulk of the commercially available global marine off-road engines, including Wärtsila (Sulzer), MAN-BW, Caterpillar and Cummins.

[11] ppm = parts per million

nels /general reference on the effect see Planco 2007/. All emissions from full and empty voyages as well as during time in port are normalized to the transport of one tkm.

Table 39: Assumption of vessel number, vessel utilization and overall transport work per year for inland vessels

Ship Type	Subtype	Cargo utilization	Number per class	Transport work per year [tkm]
Class IV	Neo K	0.45	230	2 080 000 000
Class IV	Europaschiff	0.45	670	12 699 000 000
Class Va	RoRo	0.60	186	9 430 000 000
Class Va	Tankship	0.45	128	5 841 000 000
Class Via	JOWI Schiff	0.45	12	1 545 000 000
Class Vib	Push Convoy	0.60	111	29 675 000 000
For number and transport work: Planco 2007				

The resulting emission factors with average weight cargo for container transport are presented in Table 40. The lower emission factors for container carrying inland vessels compared to the bulk carrying inland vessels are a result of the better vessel utilization rates.

Table 40: Emission factors for inland vessels. Container transport figures represent the average container load of 10.5 t/TEU.

Ship	Type	Standard type	Dead weight tons	CO2 SUM [g/t-km]	CO2 eq SUM [g/t-km]	Nox SUM [g/t-km]	SOx SUM [g/t-km]	HC SUM [g/t-km]	PM10 SUM [g/t-km]
Inland Barge	all others	EURO ship like	<2000 t	60.64	61.23	0.88	0.38	0.0237	0.0260
Inland Barge	Rhine, Mississipi waterway > Klasse V)	> class Va	>2000 t	37.74	38.11	0.65	0.24	0.0152	0.0167
Inland Barge Container	all others	EURO ship like	<2000 t	52.69	53.20	0.76	0.33	0.0206	0.0226
Inland Barge Container	Rhine, Mississipi waterway > Klasse V)	> class Va	>2000 t	31.50	31.80	0.54	0.20	0.0127	0.0139

5.4.3 Allocatin rules for inland vessels

For inland vessels the same allocation rules than for ocean going vessels apply (see chapter 5.3.4).

5.5 Aircraft transport

Air freight services include inland courier flights by small aircrafts as well as intercontinental jet flights for the transport of complete technical assets. Predominantly perishable and expensive goods are transported by air freight, and almost exclusively break bulk goods. The goods are either transported in dedicated freighters (only for freight) or together with passengers in aircrafts (so-called belly freight) /Borken 1999/. EcoTransIT World enables to calculate both the emissions of air cargo transported by freighter and the emissions of belly freight.

The next chapter provides an overview of the different types of aircrafts considered in EcoTransIT World and the load factors assumed. The methodology of calculating the flight distance is presented. The following chapters describe the calculation methodology of energy consumption as well as GHG emissions and air pollutants. Last but not least the belly freight approach to split the energy consumption and emissions of aircrafts into the passenger and freight related parts is described.

5.5.1 Type of airplanes and load factor

Different types of aircrafts are used, depending on the flight distance and the cargo volumes. Furthermore, dedicated freighter and passenger aircrafts have to be distinguished. Therefore EcoTransIt World offers a broad selection of different types of aircrafts (see Table 41).

Table 41 Type of dedicated freighter and passenger aircrafts considered

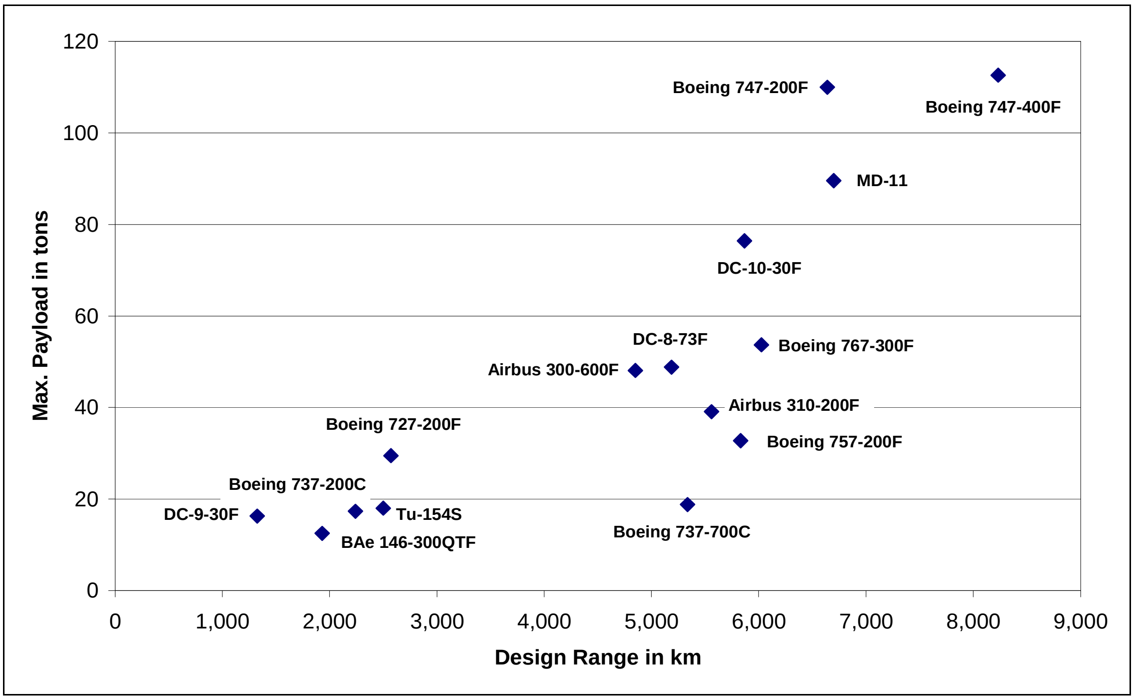
Dedicated freighters	Passenger aircraft
Airbus 300-600F	Airbus A310-200
Airbus 310-200F	Airbus A320-200
Boeing 727-200F	Airbus A330-200
Boeing 737-200C (Advanced)	Airbus A340-300
Boeing 737-700C	Boeing 727-200
Boeing 747-200F	Boeing 737-100
Boeing 747-400F	Boeing 737-400
Boeing 757-200F	Boeing 747-200
Boeing 767-300F	Boeing 747-400
McDonnell Douglas DC-8-73F	Boeing 757-200
McDonnell Douglas DC-9-30F	Boeing 767-300 ER
McDonnell Douglas DC-10-30F	Boeing 777-200
McDonnell Douglas MD-11	McDonnell Douglas DC-9-30
Tupolew Tu-154S	McDonnell Douglas DC10-30
British Aerospace BAe 146-300QTF	McDonnell Douglas M81-M88
	Fokker 100

Sources: www.airbus.com; www.boeing.com; Lang 2007; Öko-Institut.

Each aircraft is characterised by both a maximum possible range and a maximum payload (maximum freight weight). Large passenger aircrafts can fly non-stop more than 10,000 km, whereas smaller ones have maximum ranges of 2,000 to 3,000 km /Lang 2007/. Aside from that, larger aircrafts can transport heavier freight than smaller ones. EcoTransIT World includes a wide range of small, medium and large aircrafts covering the whole possible spectrum of ranges and payloads, which is shown in Figure 18.

The EcoTransIT model considers only the so-called design range, which is the maximum range when the whole structural payload is utilized /Hünecke 2008/. Beyond this range the payload has to be reduced in the amount of additional fuel needed for the longer flight.

Figure 18 Design range and maximum payload of different dedicated air freighters



Furthermore, EcoTransIT provides only aircrafts suitable for the flight distance between selected airports. If the trip distance is long, only those aircrafts are offered that are able to fly this distance. The longer flight, the fewer the types of aircrafts provided (see Figure 18). Additionally the aircrafts are distinguished between dedicated freighter and passenger aircrafts. Table 42 gives an overview of the selected aircrafts as well as their design ranges, maximum payloads and number of typical seats (only for passenger aircrafts). The characteristics of all freighter and passenger aircrafts included in EcoTransIT are available in Table 59 in the annex. In the expert modus of EcoTransIT World, all aircraft types are available and may be chosen by the user.

Table 42 Characteristics of selected aircrafts

Type	Distance Group	Type of aircraft	Aircraft code	Design Range (km)	Max. Pay-load (t)	Typical Seats (number)
Freighter	Short haul	Boeing 737-200C	B732F	2,240	17.3	
Freighter	Medium Haul	Boeing 767-300F	B763F	6,025	53.7	
Freighter	Long haul	Boeing 747-400F	B744F	8,230	112.6	
Belly Freight	Short haul	Fokker 100	F100	3,170	1.0	85
Belly Freight	Medium Haul	Boeing 757-200	B752	7,222	4	200
Belly Freight	Long haul	Boeing 747-400	B744	13,450	14	416
Sources: Lang 2007; Lufthansa Cargo 2007..						

As mentioned 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 is included within the EcoTransIT World tool. Other types of goods (bulk, average) are not available. The load factors used for volume goods differentiated by short, medium and long haul are contained in chapter 3.2.3.

5.5.2 Energy consumption and emission factors

Specific energy consumption and emissions of air cargo transportation depend heavily on the length of the flight. This is caused by different energy needs in different phases of flight. For example the take-off has the highest specific energy demand. Its share of the total flight obviously declines as the length of the flight increases. Hence EcoTransIT World contains fuel consumption and emission data of each airplane including their flight distance dependence. Furthermore, energy consumption and emissions depend on utilization of the capacity of aircrafts (load factor). 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 from there justifiable.

The basis of fuel consumption and emission data is the CORINAIR Emission Inventory Guidebook /EEA 2006/. This guidebook includes detailed information of fuel burned as well as NOx and HC emissions associated with discrete mission distances and for approximately 20 different turbojet aircraft types. The CORINAIR database uses modelled data derived from the aircraft performance model PIANO3. The data of the CORINAIR Guidebook was applied in different emission calculation tools and handbooks /ICAO 2008, DEFRA 2008/ and it is also used for EcoTransIT World. In this context, it has to be taken into account that the CORINAIR data is based on an average fleet. The calculated values may be 10% below or above the real fuel consumption and emissions of individual aircrafts connecting a concrete city pair /ICAO 2008/. Although most air carriers have detailed information of their fuel consumption and emissions, this data is not made available to the public. Thus the CORINAIR data is the best publicly available data source for the purpose of EcoTransIT World.

Table 43 shows CORINAIR energy consumptions for aircrafts selected for the standard modus of EcoTransIT relating to discrete travel distances. Fuel data of other aircrafts covered by EcoTransIT can be found in Table 59 in the annex. Since CORINAIR database contains only fuel and emission data for one aircraft model (e.g. Boeing 747-400), the data is used for both dedicated freighter and passenger aircrafts (see Table 43: Boeing 747-400F). The fuel data as well as emissions data were extrapolated to cover the maximum ranges needed. The CORINAIR database offers for some aircrafts only shorter than the real ranges (e.g. Fokker 100, Airbus A310-200, Boeing 737-400, Boeing 757-200, McDonnell Douglas DC10-30). These extrapolation steps were done by using a quadratic polynomial regression.

Table 43 Fuel consumption of selected freighter and passenger aircrafts depending on flight distances

Distance (km)	Dedicated freighter			Passenger aircrafts		
	Boeing 737-200C (kg)	Boeing 767-300F (kg)	Boeing 747-400F (kg)	Fokker 100 (kg)	Boeing 757-200 (kg)	Boeing 747-400 (kg)
232	1,800	3,030	6,331	1,468	2,423	6,331
463	2,495	4,305	9,058	2,079	3,410	9,058
926	3,727	6,485	13,405	3,212	5,070	13,405
1,389	4,950	8,665	17,751	4,286	6,724	17,751
1,852	6,191	10,845	22,097	5,480	8,391	22,097
2,778	8,722	15,409	30,922	7,796	11,846	30,922
3,704	11,438	20,087	40,267	10,400	15,407	40,267
4,630	n/a	24,804	49,480	n/a	19,026	49,480
5,556	n/a	29,909	59,577	n/a	22,348	59,577
6,482	n/a	35,239	69,888	n/a	25,683	69,888
7,408	n/a	40,631	80,789	n/a	28,968	80,789
8,334	n/a	46,314	91,986	n/a	n/a	91,986
9,260	n/a	52,208	103,611	n/a	n/a	103,611
10,186	n/a	58,557	115,553	n/a	n/a	115,553
11,112	n/a	64,501	128,171	n/a	n/a	128,171
12,038	n/a	n/a	141,254	n/a	n/a	141,254
12,964	n/a	n/a	155,563	n/a	n/a	155,563
13,890	n/a	n/a	169,088	n/a	n/a	169,088

Source: EEA 2006.

Fuel and emission data of some aircrafts which are also used for freight transport were missing in the CORINAIR database (Airbus A300-300, B737-700C, McDonnell Douglas DC-8, McDonnell Douglas MD 11, Tupolev TU-154). For theses cases other data sources were used. The fuel consumption and emissions of the Airbus A300-300 are directly taken from the Piano model /Piano 2008/. All other information are derived from a database created on behalf of the German Federal Environmental Agency /UBA 2000/. The fuel consumption and emission values are transferred to the distances used within the CORINAIR database because the data refers to other distances. The calculated fuel consumption figures of these aircrafts are also presented in Table 59 in the annex. In principle the energy consumption of every aircraft selected by an EcoTransIT World user will be taken from Table 59. The corresponding fuel consumption of flight distances between those listed in the table are calculated by linear interpolation.

The NOx and NMHC emissions are derived in the same way like the fuel consumption data /EEA 2006; Piano 2008; DLR 2000/. Table 44 shows the results for the aircraft type Boeing 747-400. All databases contain only data for HC. For CH_4 it is assumed that the emission factors for the Landing and Take-Off cycle (so-called LTO cycle, <1,000 m altitude) be 10% of total HC emissions, while during cruise no methane is emitted /EEA 2006/. Consequently the remaining HC emissions are NMHC emissions.

Table 44 Energy consumption and CO_2, NOx, HMHC and PM emissions of aircraft type Boeing 747-400

Distance (km)	CO_2 (tons)	NO_X (kg)	NMHC (kg)	PM_{dir} (kg)
232	20	119	5.7	0.9
463	29	168	9.2	1.5
926	42	227	11.0	2.3
1,389	56	281	11.6	3.2
1,852	70	336	12.3	4.1
2,778	97	447	13.7	5.8
3,704	127	574	15.1	7.7
4,630	156	687	15.9	9.5
5,556	188	827	17.5	11.6
6,482	220	973	19.1	13.6
7,408	254	1,137	20.8	15.8
8,334	290	1,311	22.5	18.0
9,260	326	1,492	24.2	20.4
10,186	364	1,687	25.7	22.8
11,112	404	1,900	27.6	25.3
12,038	445	2,129	29.6	27.9
12,964	490	2,343	31.2	31.1
13,890	533	2,578	32.8	33.9
Sources: EEA 2006, Öko-Institut estimations.				

All other emissions (CO_2, N_2O, SO_x, PM) and are calculated on the basis of fuel-based emissions factors which are provided in Table 45. The CO_2 emissions resulting for a Boeing 747-400 are shown in Table 44. With regard to PM emissions Table 45 contains only the fuel-based emission factor for climb, cruise and descent without the LTO cycle /Öko-Institut 2009/. The emission factors for the LTO cycle depend on the type of aircraft. The total PM emissions are the sum of LTO emissions and fuel-related emissions during cruise.

Table 45: Fuel-based emission factors for CO_2, N_2O, SO_x and PM_{dir}

	g/kg fuel
Carbon dioxide (CO_2)	3,150
Laughing gas (N_2O)	0.10
Sulphur dioxide emissions (SO_x)	1.00
PM_{dir} (only Climb/Cruise/Descent)	0.20
Sources: EEA 2006; Öko-Institut 2009.	

RFI factor

The climatic impacts of the different pollutants can be converted to those of carbon dioxide. This is done using the “Radiative Forcing Index” (RFI, see /IPCC 1999/ and short description in /Atmosfair 2009/). The RFI Factor takes into account the climate effects of other GHG emissions (in particular nitrogen oxides, ozone, water, soot, sulphur), especially for emissions in high altitudes. The result is a quantity of CO_2 that would have to be emitted to cause the same warming effect, when averaged globally, as the various pollutants together. Air traffic causes an additional global warming in altitudes above nine kilometres. These altitudes are usually reached in the cruise phase of flights with distances greater than approx. 400–500 km /Atmosfair 2007/. Therefore in EcoTransIT World the use of the RFI factor is included as an option for flights with distances over 500 km.

For cruise in critical altitudes over 9 kilometres a RFI factor of 3 is used (this means that the direct CO2 emissions of cruise are multiplied by 3). This value is also used by ATMOSFAIR. A recent publication of the German Federal Environmental Agency state a RFI factor of even 3-5, if the effects of cirrus is included /UBA 2008/. With these assumptions the average RFI factors depending on flight distance described in Table 46 are used in EcoTransIT World.

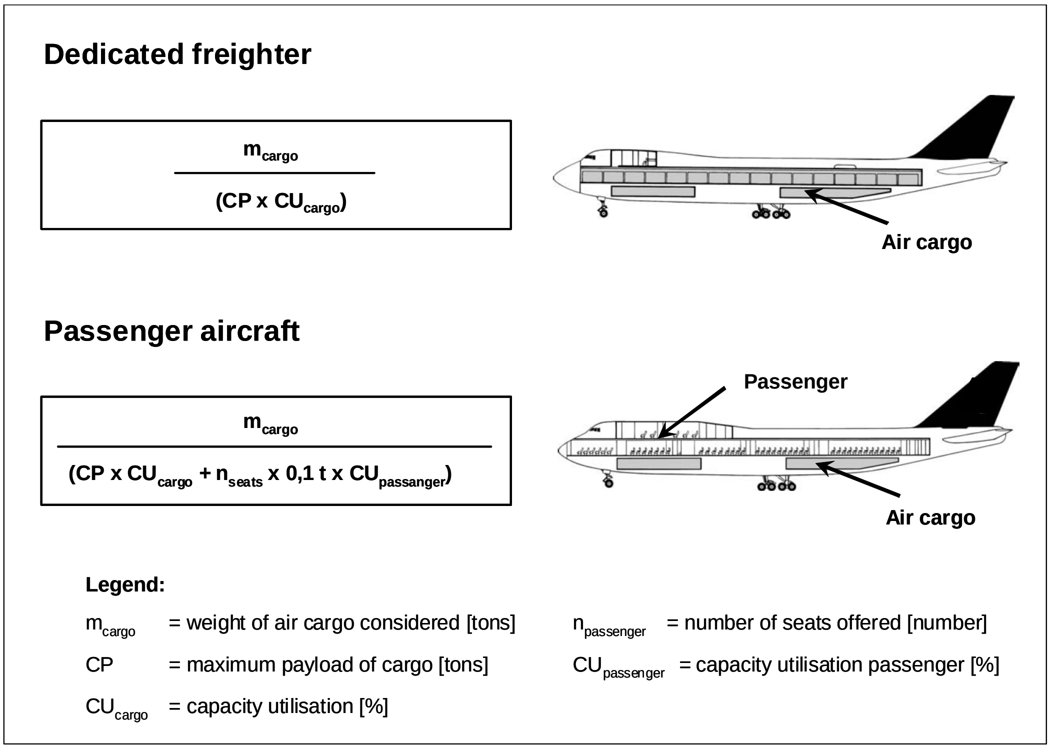
Table 46 RFI factor depending on flight distance

Distance (km)	Share of distance over 9,000 m (%)	Average RFI-Faktor
500	0%	1.00
750	50%	.1.81
1,000	72%	2.18
2,000	85%	2.52
4,000	93%	2.73
10,000	97%	2.87
Sources: DLR 2000; Atmosfair 2009; Öko-Institut estimations.		

5.5.3 Allocation method for belly freight

The allocation of emissions between passenger and freight utilizes a mass based approach. The energy consumption and emissions of dedicated freighters are simply allocated 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). The allocation approach of belly freight is more sophisticated. With belly freight the energy consumption must be split between air cargo and passenger. This is done by taking into account the weight of the passengers and the passenger capacity utilisation (load factor). In accordance with the EU Directive to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community a weight of 100 kg (= 0.1 t) per passenger is assumed. Figure 19 contains the concrete formula to allocate the energy consumption and emissions of passenger aircrafts.

Figure 19 Allocation rules for dedicated freighter and passenger aircrafts



Dedicated freighter

$$\frac{m_{cargo}}{(CP \times CU_{cargo})}$$

Passenger aircraft

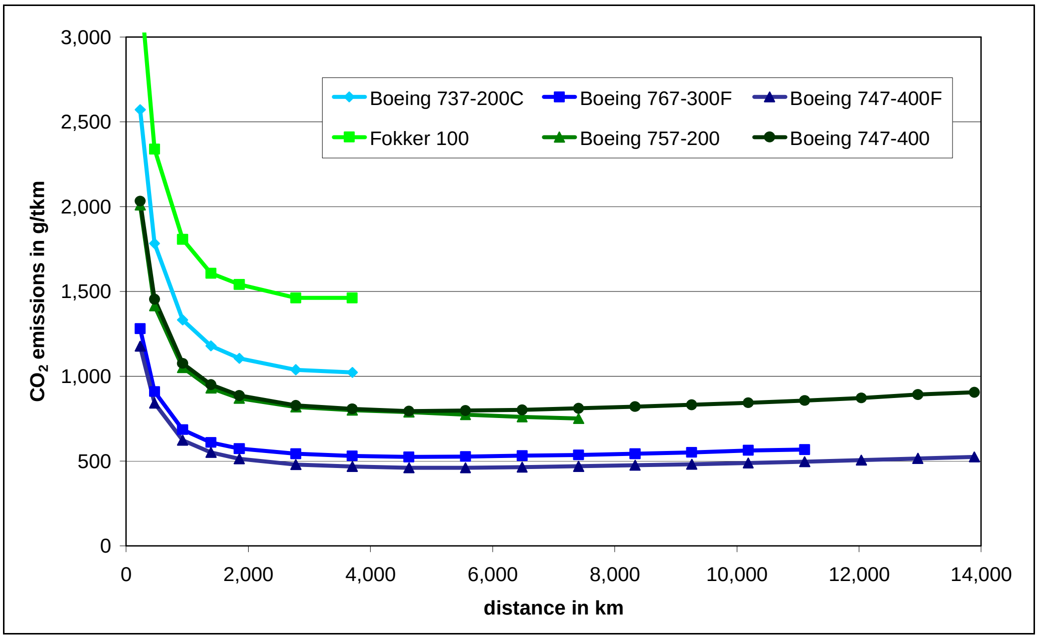
$$\frac{m_{cargo}}{(CP \times CU_{cargo} + n_{seats} \times 0{,}1\ t \times CU_{passanger})}$$

Legend:

m_{cargo} = weight of air cargo considered [tons]
CP = maximum payload of cargo [tons]
CU_{cargo} = capacity utilisation [%]
$n_{passenger}$ = number of seats offered [number]
$CU_{passenger}$ = capacity utilisation passenger [%]

This formula, which is commonly used for belly freighters, leads to higher fuel consumption and emissions of air cargo carried by passenger aircrafts compared to that of air transport with freighters. As Figure 20 shows for the selected aircrafts within the standard modus of EcoTransIT World, the CO_2 emissions of belly cargo is 40 to 70% higher as air cargo transported by dedicated freighters. Additionally the figure shows that the specific CO_2 emissions of smaller aircrafts (e.g. B737-200C) 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 manly used for long haul flights over 3,700 km.

Figure 20 Specific CO_2 emissions of dedicated freighter (B 737-200C, B 767-300F, B 747-400F) and passenger aircrafts (Fokker 100, Boeing 757-200, Boeing 747-400) in g/tkm



5.6 Energy and emissions of the upstream process

Additional to the emissions caused directly by operating the vehicles all emissions and the energy consumption of the **generation of final energy (fuels, electricity)** are taken into account (see Figure 1 on page 7). The impacts of building the infrastructure for extraction and generation of the different energy carrier are also included.

The main energy carriers used in freight transport processes are liquid fossil fuels such as diesel fuel, kerosene and heavy… and electricity. To compare the environmental impacts of transport processes with different energy carriers, the total energy chain has to be considered:

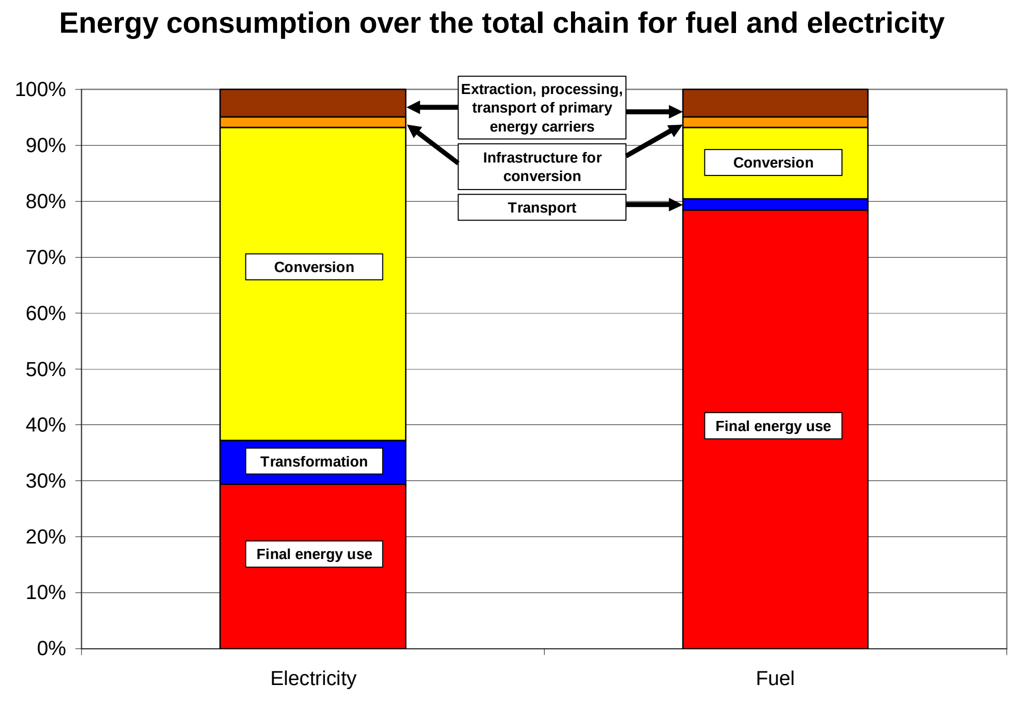
Energy chain of electricity production:

- 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 deposal 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
- Energy distribution (transport to service station, filling losses)

Figure 21 Energy chain for diesel fuel and electricity with exemplary efficiency



Note: Schematic presentation by IFEU

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 other environmental impacts on human health and ecosystems.

5.6.1 Exploration, extraction, transport and production of diesel fuel

The emission factors and energy demand for the construction and disposal of 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 /Ecoinvent 2009/ The following table shows the specific figures for the emissions and the energy consumption for the prechain.

Table 47 Emission factors and energy consumption for energy production of liquid fuels

	Efficiency	CO_2	NOx	SO_2	NMVOC	PM
		kg	g	g	g	g
Gasoline	75%	0.67	2.11	5.81	2.11	0.29
Diesel, MDO, MGO	78%	0.47	1.80	4.39	1.52	0.23
Biodiesel	60%	0.89	6.32	1.64	1.14	0.72
Kerosene	79%	0.45	1.76	4.30	1.51	0.23
Heavy fueloil	79%	0.40	1.68	3.99	1.47	0.21
Efficiency: final energy related to primary energy [%] Emission factors: emissions related to final energy [kg fuel] Source: /Ecoinvent 2009/						

5.6.2 Electricity production

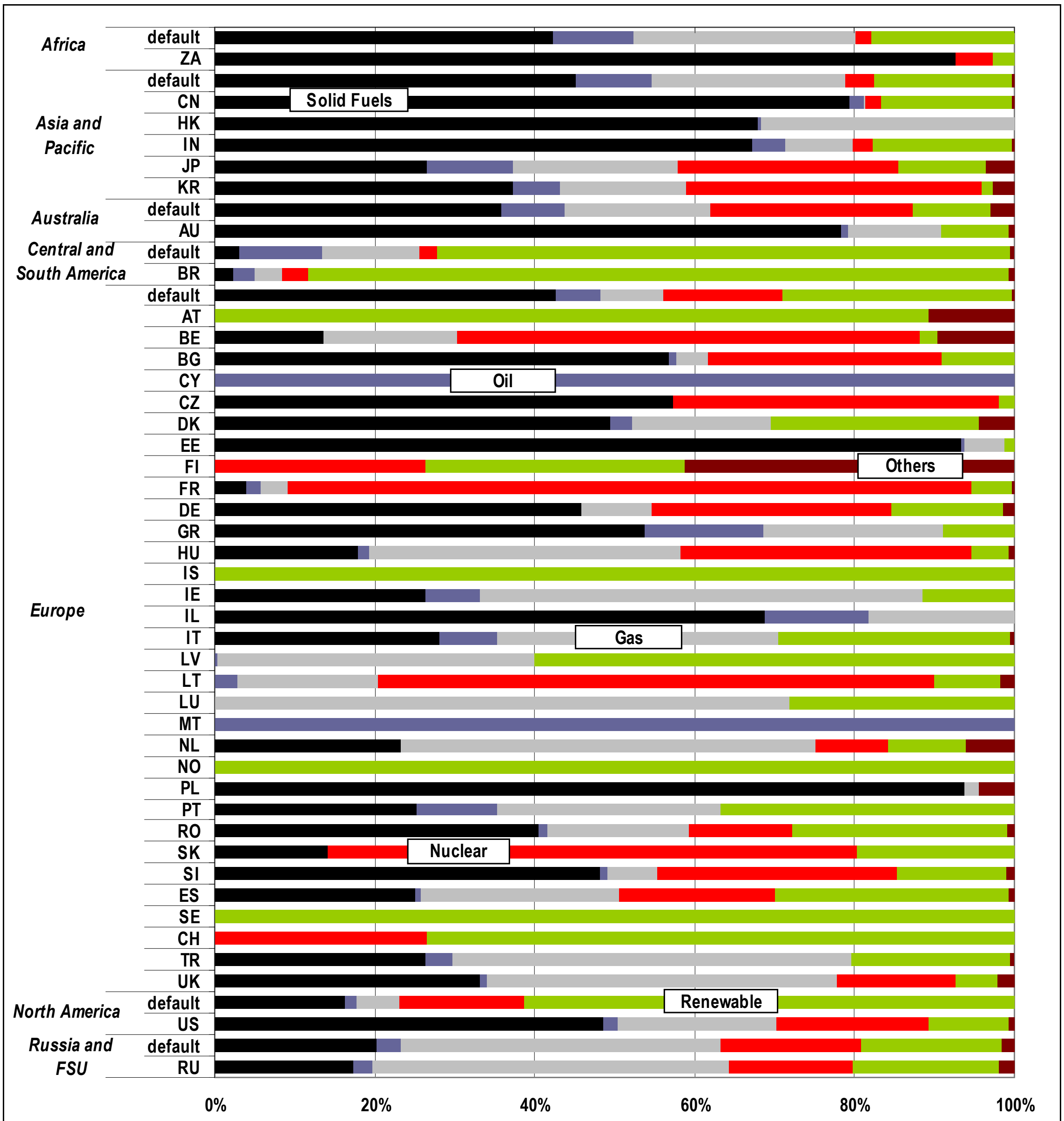
The emission factors of electricity production depend mainly on the mix of energy carriers and the efficiency of the production. The main problem of quantifying ecological impacts of electricity is that electrons cannot, in actuality,, be traced to a particular power plant. Special properties of electricity have to be considered:

- Each country has its own electricity production mix; in some countries the railways have, at least partially, their own power plants or buy a special mix of electricity.
- The split of production differs between night and day and also between winter and summer. For example gas-fired power plants can more easily accommodate changes in the power demand than coal fired power plants. This means that during the night the percentage of electricity that is generated by coal is higher than during the day. The emissions of a coal-fired plant are usually higher than those of a gas fired plant.
- The liberalisation of the energy market leads to an international trade of electricity making the determination of a specific electricity mix even more difficult.
- For combined production of heat and power (CHP) the total efficiency of the energy production is higher (see following chapter).

The most accepted method to estimate emission factors for electricity production is to use the average electricity split per year and country or, where available, the single railway-specific average. Transport occurs night and day and over the whole year. Therefore, it makes sense to use this assumption.

The values for the Energy mix of the electricity production are taken from the UIC Energy and CO_2-Database /UIC 2009/ and if no values are available data from EU /Eurostat 2009/ or IEA-statistics /IEA 2007a/. In the following figure the used values are shown (Table in appendix 6.5):

Figure 22 Energy split of electricity consumption used by railways



Sources: /UIC 2009/ (railway mix); /Eurostat 2009/, /IEA 2007a/ (national mix)

The data for CHP are taken from /Eurelectric 2008/ for the most of the European countries and from IEA-statistics for the others (share of electricity generation in CHP on total electricity production). The following table shows the values used:

Table 48 Energy efficiency and emission factors of the electricity supply for railway transport

Region	Code	Share CHP*	Efficiency	CO2	NOx	SO2	NMVOC	PM10
		[%]	[%]	kg/kWh	g/kWh	g/kWh	g/kWh	g/kWh
Africa	*default*	0%	31%	0.746	1.553	2.315	0.173	0.143
	ZA	0%	27%	1.016	2.258	3.326	0.101	0.247
Asia and Pacific	*default*	0%	30%	0.763	1.546	2.577	0.160	0.166
	CN	13%	32%	0.998	3.743	8.290	0.048	0.756
	HK	0%	27%	0.960	1.910	2.541	0.170	0.187
	IN	5%	31%	0.818	1.763	2.777	0.111	0.197
	JP	3%	28%	0.581	1.178	1.916	0.123	0.122
	KR	9%	28%	0.565	1.190	1.839	0.110	0.122
Australia	*default*	0%	28%	0.651	1.227	2.504	0.124	0.168
	AU	7%	28%	0.972	1.797	3.679	0.106	0.279
Central and South America	*default*	0%	54%	0.225	0.500	0.976	0.087	0.051
	BR	1%	69%	0.092	0.174	0.426	0.026	0.033
Europe	*default*	0%	31%	0.681	0.939	3.645	0.067	0.273
	AT	27%	77%	0.112	0.095	0.079	0.007	0.024
	BE	8%	26%	0.381	0.769	1.321	0.055	0.104
	BG	8%	29%	0.607	1.338	1.959	0.074	0.145
	CY	0%	26%	0.951	3.049	7.301	0.428	0.226
	CZ	23%	31%	0.657	1.039	1.238	0.019	0.057
	DK	77%	56%	0.390	0.440	0.794	0.056	0.042
	EE	16%	26%	1.192	1.401	6.649	0.046	0.524
	FI	38%	35%	0.452	0.511	1.806	0.024	0.138
	FR	4%	26%	0.073	0.225	0.316	0.024	0.025
	DE	13%	32%	0.527	0.489	0.422	0.055	0.044
	GR	11%	22%	0.980	1.142	4.432	0.138	0.618
	HU	22%	24%	0.589	0.748	0.818	0.259	0.049
	IS	0%	87%	0.010	0.029	0.029	0.008	0.019
	IE	2%	30%	0.733	1.157	2.377	0.217	0.119
	IL	0%	27%	1.002	2.200	3.520	0.184	0.220
	IT	31%	46%	0,464	1,093	1,542	0,160	0,100
	LV	28%	70%	0.150	0.183	0.071	0.068	0.014
	LT	18%	30%	0.102	0.173	0.196	0.049	0.014
	LU	10%	26%	0.692	0.802	0.256	0.312	0.024
	MT	0%	26%	0.952	3.050	7.304	0.429	0.226
	NL	58%	40%	0.483	0.685	0.533	0.068	0.046
	NO	1%	70%	0.006	0.018	0.008	0.003	0.013
	PL	22%	28%	1.018	1.751	4.748	0.050	0.303
	PT	14%	39%	0.523	1.442	3.083	0.161	0.103
	RO	22%	37%	0.543	0.662	2.608	0.059	0.208
	SK	18%	29%	0.196	0.395	2.178	0.011	0.208
	SI	3%	31%	0.678	1.610	11.150	0.041	0.297
	ES	12%	38%	0.399	1.284	2.042	0.066	0.164
	SE	7%	91%	0.004	0.014	0.006	0.003	0.016
	CH	1%	54%	0.005	0.019	0.012	0.004	0.012
	TR	5%	32%	0.690	0.949	2.075	0.175	0.154
	UK	8%	34%	0.586	1.043	1.328	0.076	0.097
North America	*default*	2%	46%	0.253	0.381	1.167	0.033	0.097
	US	8%	27%	0.732	1.420	4.091	0.156	0.073
Russia and FSU	*default*	0%	31%	0.548	0.890	1.310	0.154	0.094
	RU	31%	37%	0.431	0.653	0.993	0.126	0.074

* Share of electricity generation in CHP on total electricity production
Sources CHP: /Eurelectric 2007/, /IEA 2007a/, /IEA 2007b/, /IEA 2008/

Allocation of electricity from CHP and its environmental impacts

In some cases electricity for rail transport is produced in power plants producing both electricity and heat (cogeneration or Combined Heat and Power - CHP). Therefore the environmental impacts of running the power plant have to be burdened (allocated) on both output products. As well. Amongst others the following allocation methodologies are feasible:

1. Allocation by Energy
2. Allocation by Exergy
3. Approach mentioned in /Directive 2004/8/EC/

The *allocation by energy* is based on the assumption that one unit of heat is equivalent to one unit of electricity. This assumption is also the main disadvantage of this approach, because in regards to thermodynamics electricity has a higher work potential than heat. So the more valuable product of cogeneration is electricity and actually has to be burdened with more environmental impact units than heat. Thus this allocation methodology favours electricity.

In contrast the *allocation by exergy* is considering the different valence of electricity and heat. In /Heck 2004/ one unit electricity is equivalent to 0.17 unit heat. This methodology is favoured by scientific institutions (e. g. IFEU) but does not represent an approved European standard for CHP allocation so far.

Compared to the allocation by exergy the approach mentioned in */Directive 2004/8/EC/* (also called “Finnish Methodology”) represents a European wide accepted methodology. It was developed to calculate the efficiency of new CHP power plants. Therefore the difference (reduction) between the production in CHP and the production in a separate heat and a separate electricity power plant is estimated. The default values for the separate production are defined by /Decision 2007/74/EC/. The methodology does not take the different valence of electricity and heat into account (cp. exergy). But electricity gets a lower environmental benefit compared to the allocation by energy. And this methodology is approved within the European Union. Thus we use this approach to allocate the environmental impacts of cogeneration.

The following table shows the effect of using the three described allocation methodologies on the overall efficiency and CO_2-emission factor:

Table 49 Comparison of different methodologies to allocate environmental impacts of electricity from cogeneration

	Denmark	Germany
Efficiency of total electricity generation*		
w/o Allocation**	36%	30%
1. Energy	70%	33%
2. Exergy	43%	31%
3. Directive 2004/8/EC (Finnish Methodology)	56%	32%
Specific CO_2-emissions of total electricity generation* [kg/kWh]		
w/o Allocation**	0,636	0,586
1. Energy	0,302	0,508
2. Exergy	0,524	0,558
3. Directive 2004/8/EC (Finnish Methodology)	0,390	0,527

* incl. electricity from CHP and conventional electricity generation (total electricity mix)
** electricity from CHP is estimated like non-CHP electricity (allocation factors: 100% electricity; 0% heat)
Source: IFEU

5.7 Intermodal transfer

Intermodal transfer can be relevant in a comparison of two transport variants, i.e. if one transport variant requires more transfer processes than the other. Therefore the transhipping processes are classified in container, liquid, bulk and other cargo. On basis of assumptions and previous IFEU-studies the energy use of the different transfer processes is estimated. Approach and estimation of the values are described below.

Container:	The energy used by a handling container in a rail cargo transport centre was estimated by /IFEU°2000/ with 4.4 kWh per transfer process. In other previous studies /ISV°1993, IFEU°1999/ a lower value (2.2°kW h/°transfer) for rail was assessed. For container transfer in ship cargo transport centres these studies searched out an energy factor twice than rail /ISV°1993/. Because of high uncertainties the value of 4.4 kWh per transfer process is assumed for all carriers.
Liquid cargo:	In /ISV°1993/ a very detailed calculation of the energy demanded by transhipping diesel was carried out. For the different carriers the values range from 0.3 to 0.5 kWh/t, for which is why 0.4 kWh/t as average energy use is assessed.
Bulk cargo:	The results of early IFEU-estimations searching out the energy use of unloading corn from different means of transport were used in /ISV°1993/. For bulk cargo transfer the previous value 1.3 kWh/t is also used in EcoTransIT.
Other cargo:	In this category all cargo, which is not container, liquid or bulk cargo is summarised. Thus the value for energy use of transhipping cargo of this category has the highest uncertainty. On basis of /ISV°1993/ a factor of 0.6 kWh/t for this category is taken. ,

6 Appendix

6.1 Additonal information to load factors

In this chapter some explanations about the load factor of trucks, trains and containers are givan in addition to chapter 3.2.2.

6.1.1 Truck

Five truck types are available in EcoTransIT. The following table shows default values of capacity and load factors for different lorry types.

Table 50 Capacity for different truck types and load factor

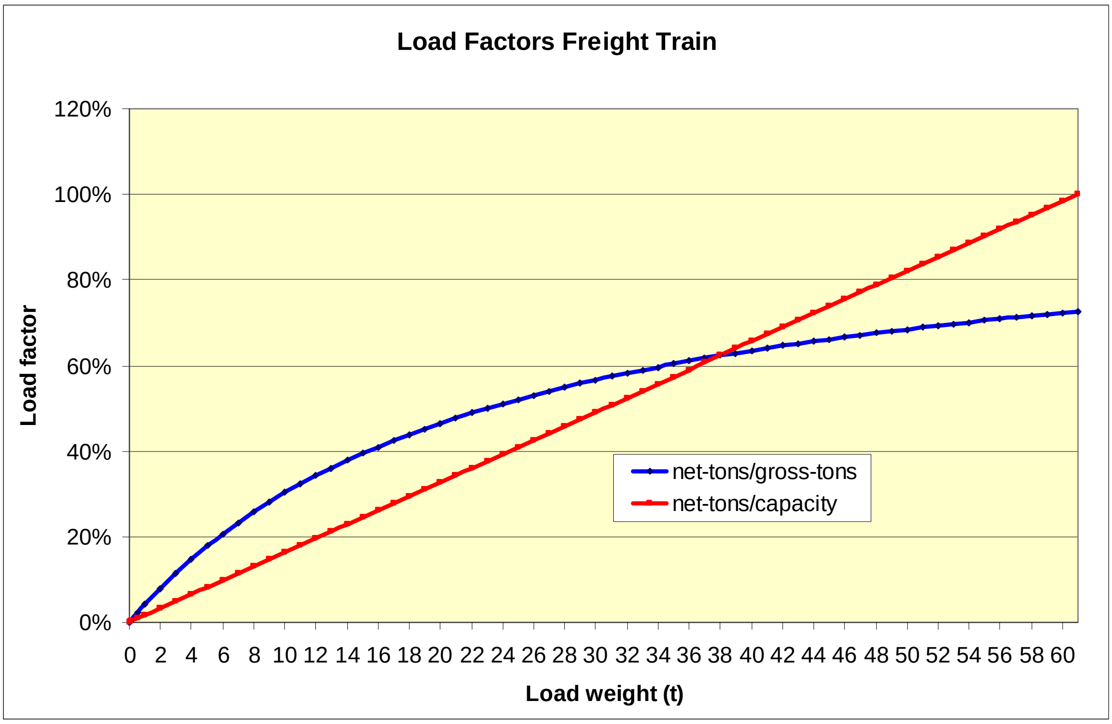
	< 7,5 gross hauled tonnes	7,5 - 12 gross hauled tonnes	Truck 12-24 gross hauled tonnes	Truck train or articulated truck 24-40 gross hauled tonnes	Truck train 40 - 60 gross hauled tonnes
Capacity (tons)	3.5	6	12	26	38
Load Factor (freight weight/capacity)	Freight weight (tons)				
10%	0.35	0.6	1.2	2.6	3.8
30% (volume freight)	1.05	1.8	3.6	7.8	11.4
50%	1.75	3	6	13	19
60% (average freight)	2.1	3.6	7.2	15.6	22.8
100% (bulk freight)	3.5	6	12	26	38

6.1.2 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 with the following default values for the average wagon defined in EcoTransIT (see chapter 3.2.1: empty weight: 23 tonnes, payload capacity: 61 tonnes):

The following figure shows a comparison of the load factors for freight trains, based on this key values.

Figure 23 Load factors for freight trains



6.1.3 Container

Many cargoes shipped in containers are light weight consumer goods[12]. The per TEU-km emissions are allocated to the net-load of the container. Since emissions of container vessels are calculated on a g/TEU-km basis and energy consumption of the ship only marginally depends on the load of the container, volume and average weight cargo is responsible for higher emissions on a per tonne-kilometre basis than heavy weight cargo. Three container load classes are provided as default values (see Table 51).

Average cargo

A study of port container statistics results in an average weight per 20' standard container of 10.5 tonnes[13], which is used as default average load for one TEU. Cargo is transported in 20' and 40' containers in the ratio of approximately 2 to 5, i.e. 2 TEU to 10 TEU[14]. Thus, for each

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

[13] Port statistics of the Ports of Amsterdam, Rotterdam, Hamburg, Bremerhaven, Seattle, Singapore, Hong-Kong and Sydney.

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

lift[15] an average of 1.7 TEUs is loaded. The average empty weight of a TEU is 1.95 tonnes[16]. Thus the average gross weight of a TEU is 12.45 tonnes, which corresponds well with the maximum carrying capacity of common container vessels if most of the container spaces were filled. In order to determine average heavy weight and light weight cargo the following assumptions and calculations were made:

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) tend 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. The light weight is then assumed to be using 50 % of the carrying capacity. Thus, a 40’ Container filled 45 %[17] to its weight carrying capacity is assumed to represent a light weight cargo container. This results in 6.0 tonne/TEU and an average empty container weight of 1.9 tonnes.

Heavy weight cargo:

The default heavy weight TEU load is derived similarly. Here 90 % of the maximum carrying capacity of the containers is assumed to represent the heavy weight cargo. In order to determine the average heavy weight, the use of 20’ and 40’ containers for heavy weight cargo need to be determined. Applying the 1.7 ratio 40’ to 20’ Container results in approximately 5x 40’ containers and 2x 20’ containers or 12 TEUs. In the set of 12 TEUs and 7 containers, a ratio of 3x 40’ containers filled with volume weight cargo and 2x 40’ containers plus 2x 20’ containers filled with heavy weight cargo result in the overall average weight of 10.5 tonnes. The heavy weight containers are then filled with 14.5 tonnes per TEU on average[18].

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 51: Container net-cargo weights for EcoTransIT cargo categories (netto weight)

Light weight cargo	Average cargo	Heavy weight cargo
6 metric tonnes/TEU	10.5 metric tonnes/TEU	14.5 metric tonnes/TEU

If goods are transported as weight restricted cargo, users should be careful not to overestimate

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[15] Lift is an expression from container terminals and describes the number of containers loaded onboard of vessels.

[16] Calculated from a mix of 20’ and 40’ containers.

[17] 50 % of the container weight capacity utilized to a maximum of 90 %.

[18] Assuming a maximum utilization by weight of 90 %.

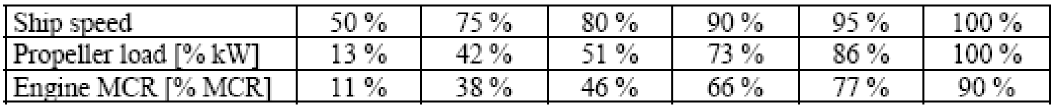
the pay load of the container. Even if a 20’ container can carry more than 21 tonnes of cargo, the on-carriage vehicle may not be able to carry that weight. The maximum gross weight of a 20’ container of 24 tonnes requires an on-road truck >32 tonnes gross vehicle weight, usually used to pull flat beds. 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 10 on page 6 provides the values used in EcoTransIT World.

6.2 Detailed derivation of Individual Vessel Emission Factors

In order to develop vessel specific emission factors at sea, emissions are calculated for one hour of transport services, using the vessels design speed, cargo capacity and vessel utilization factor. It is assumed that the design speed is achieved at 90% of the maximum continuous rating (MCR). This corresponds to the opinion of IMO /Buhaug et al. 2008/. EPA /2009/ assumes an average engine load of 83% in order to achieve the design speed. IMO chooses a 10 % service margin to prevent overload as a sufficient safety margin (sea margin), which is supported by members of the industry[19]. The results are of certain relationships between vessel speed, propeller load and engine load (Table 52)

Table 52: Speed, propeller and engine load relations. (Buhaug et al. 2008, p. 26)



Ship speed	50 %	75 %	80 %	90 %	95 %	100 %
Propeller load [% kW]	13 %	42 %	51 %	73 %	86 %	100 %
Engine MCR [% MCR]	11 %	38 %	46 %	66 %	77 %	90 %

For all pollutants the required engine power per tonne-km is calculated. Thus a theoretical value for a one hour journey is calculated by:

$$P_{tkm} = \frac{ME_{MCR} \times ME_{load}}{Vi \times c \times u}$$

With:

P_{tkm} = Required Engine power per tonne-km [kWh/t-km];ME_{MCR} = main engine maximum continuous rating; ME_{load} = main engine load factor; Vi = vessel speed at engine load [km/h]; c = vessel nominal capacity [DWT]; u = vessel utilization factor.

The engine power per t-km is the basis for calculating the emission factors of PM, CO and HC.

Multiplying the required engine power (P) with the engine specific fuel consumption (sfc) factor

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[19] Own communications with industry, fall 2008.

results in the main engine related fuel consumption per tonne-km. Specific fuel consumption factors are reliable figures and may be obtained for example from engine manufacturers. There are only two main engine manufacturers (OEM) that equip the vast majority of marine vessels. Engine specific sfc values are guaranteed by engine manufacturers with a 5% uncertainty margin. Experience shows that the real fuel consumption lies rather on the upper end of the OEM figure because of particular test bed conditions and the use of distillate fuels for sfc testing. The sfc factors were used according to Buhaug et al. /2008/ differentiated by vessel size and age. It ranges between 175 and 215 g/kWh.

$$Vfc = P_{tkm} \times sfc$$

With:
Vfc = vessel specific fuel consumption per tonne-kilometre.

The vessel specific fuel consumption per tonne-km is then multiplied with applicable emission factors for those pollutants that are based on fuel consumed (CO_2, CH_4, N_2O, NOx and SOx).. Hereby a certain split between heavy fuel oils (HFO) and distillate fuel oils (MDO and MGO) was assumed. The split was taken from a survey by ENTEC /2002/ and is vessel type specific. In addition to the ENTEC data, all 4-stroke engines were assumed to be medium speed engines that use distillate diesel oils. Steam turbines have been ignored for this project because of their minor role in marine transport. Engine based emissions are derived by multiplying P_{tkm} of sfc_{tkm} with the appropriate emission factor.

In addition to the emissions from main engines at sea, auxiliary engines operate during the voyage at sea as well as in ports. At sea they supply the vessel with electric power to operate instruments and navigational devices. In port they also supply power for the same purposes and in addition, depending on the vessel type, may power loading and discharging gears (cranes, pumps etc.). Some vessels operate main shaft electric cogeneration units that provide the bulk electric power at sea. Activity data (engine load factors) for auxiliary engines was taken from EPA /2009/. Emissions from auxiliary engines at sea and in port are added up for a standard year and then broken down to one tonne-kilometre transport work.

Auxiliary engine’s fuel consumption at sea:

$$AUXs_{fctkm} = \frac{AUX_p \times AUX_{ls} \times 24 \times d_s}{V \times 24 \times d_s \times c \times u} \times fc$$

With:
AUXsfctkm = fuel consumption of auxiliary engine per t-km at sea; AUX_P = total auxiliary engine(s) power; AUX_{ls} = auxiliary engine load at sea; d_s = days at sea; V = vessel speed; c = vessel capacity; u = average capacity utilization; fc = auxiliary fuel consumption.

Auxiliary engine’s fuel consumption in port:

$$AUXp_{fctkm} = \frac{AUX_p \times AUX_{lp} \times 24 \times d_p}{V \times 24 \times d_s \times c \times u} \times fc$$

With:
AUXp fctkm = fuel consumption of auxiliary engine in port, normalized to one t-km; AUX_{lp} = auxiliary engine load in port; d_p = days in port;

The theoretical standard year was constructed for each vessel. The standard year is based on (Sources of information are in parenthesis):

- The vessel operating at 90% MCR and cruise speed /Lloyds 2009/
- The main engines fuel consumption based on age and size /Buhaug et al. 2008/
- The vessel's capacity /Lloyds 2009/ and average vessel utilization per size and class /Buhaug et al. 2008/
- The vessel size and class being at sea for a dedicated days per year /Buhaug et al. 2008/
- The vessel being in port for the reminding days per year /Buhaug et al. 2008/
- The auxiliary engine load factors at sea and in port /EPA 2009/
- The auxiliary engine fuel consumption based on size /Buhaug et al. 2008/

The following iterative steps add the vessel's emissions from the main engine at sea, the emissions from the auxiliary engine at sea and the emissions from the auxiliary engine in port, all normalized to one tonne-kilometre. Container vessel emissions are calculated based on container capacity, because the number of loaded containers is the more relevant figure than the net cargo weight loaded into a container. Thus the underlying emission factors have the format g/TEU-km and are subsequently converted to g/t-km based on the determination of the type of cargo, or inserting the net-cargo weight per TEU.

Table 53: Sample base emission factors for bulk and container vessels on particular trade lanes for emissions from main and auxiliary engines at sea and in port.

Vessel types (BC = bulk carrier; CC = container vessel GC = general cargo ship)	Trade and Vesselcategory names	Main Engine CO_2 g/t-km [cc: g/TEU-km] at sea	Auxiliary Engine CO_2 g/t-km [cc: g/TEU-km] at sea	Auxiliary Engine CO_2 in port [g], normalized to t-km [cc: TEU-km]
BC (liquid, dry, and General Cargo)	Suez trade	4.45	0.14	0.26
BC (liquid, dry, and General Cargo)	Transatlantic trade	6.16	0.28	0.38
BC (liquid, dry, and General Cargo)	Transpacific trade	5.18	0.20	0.31
BC (liquid, dry, and General Cargo)	Panama trade	6.16	0.28	0.38
BC (liquid, dry, and General Cargo)	Other global trade	6.16	0.26	0.39
BC (liquid, dry, and General Cargo)	Intra-continental trade	8.19	0.40	0.54
CC	Suez trade	138.68	6.33	8.21
CC	Transatlantic trade	158.30	10.93	8.58
CC	Transpacific trade	156.21	9.74	8.55
CC	Panama trade	158.30	10.93	8.58
CC	Other global trade	171.42	12.69	8.83
CC	Intra-continental trade non EU	179.83	15.55	9.01
CC	Intra-continental trade EU	214.69	18.09	12.93
CC	EU SECA trade	215.95	18.20	13.01
Great Lakes BC		11.80	0.66	0.62

6.3 Guidance on deriving marine container vessel load factors for major trade-lanes

To date container vessel emission factors are often presented in g/TEU-km based on the nominal cargo capacity (100 % utilization). There are several reasons why vessel utilization can not be 100% with container vessels.

- Vessels pick-up and deliver at multiple ports, thus they sequentially load and unload in several ports and only maximize the cargo on board of the main journey;
- Ocean carriers prepare for peak seasons, for example the summer container trade for the Christmas consumer period;
- Vessels depart on schedule and not when fully loaded, which leads to empty spaces outside peak seasons.
- Ocean carriers hold overcapacities in lucrative trades in order to avoid the need to reject clients/cargo. [33]
- Ocean carriers build overcapacities when buying new ships because of long ship lives and economic growth forecasts. [B. Volk, FH Oldenburg - FB Seefahrt] [20]

For major trade-lanes the utilization was further differentiated, by using TEU trade flow data from /UNCTAD 1999-2009/. Due to the trade imbalances the return leg is often more empty than the leg that is the economic driver for the trade.[21] Thus a vessel is assumed to be loaded with 85 % Asia to Europe, but only be 53 % from Europe to Asia due to the trade flow imbalance. Over the past decade, the trade imbalance has continuously widened until 2007. In 2008 this imbalance closed slightly. Figure 24 exemplifies this on the major trade lanes (Trans-Pacific: Asia – North America; Trans-Atlantic: North America – Europe; Trans-Suez: Europe – Asia) trade. The default mode for container vessels <7000 TEU in EcoTransIT World is set to a global average of 65 %, this of 7000 TEU vessels and larger to 70 % assuming fewer port of calls and higher economic incentives to reach a maximum load of 90 %. Users are able to alter this factor according to their needs. Table 54 provides the average utilization factors for the three major trade lanes in the past five years as a reference.

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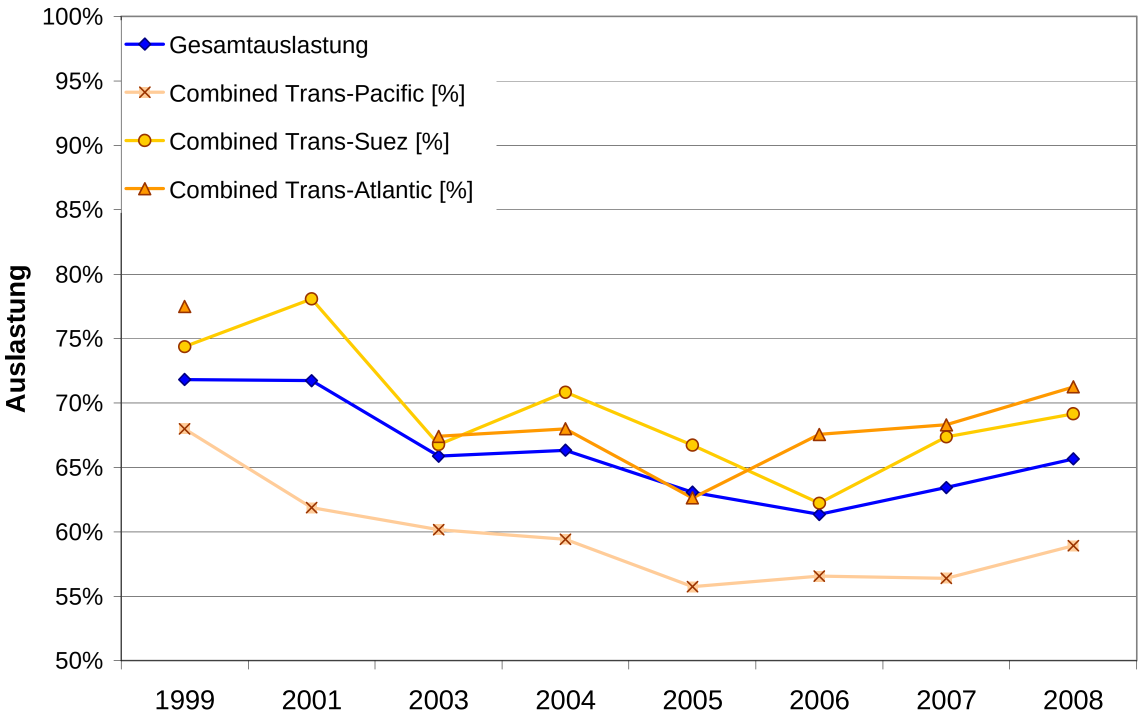
[20] The later two points are true for healthy economic markets. Due to the economic crisis the situation has changed drastically. According to the latest revisions of the WTO, global trade will decline by at least 10 per cent in volume terms in 2009 /WTO, 2009/. German seaports report drops in container trade by up to 35% in 2009 compared to the former year and up to 50% for auto trades /Handelsblatt 2009/. The economic slow down rather has increased overcapacities and likely reduced vessel utilization. However, in EcoTransIT World average vessel utilization in healthy world trade conditions are assumed.

[21] Empty container carriage here is not considered carrying cargo.

Table 54: Average utilization figures for the three major trade lanes and for the past five years, assuming a maximum utilization of 85 %. Data source: /UNCTAD 2005, 2006, 2007, 2008, 2009/.

Year	Asia – North America	Asia – Europe	Europe – North America
2004	59.4 %	70.8 %	68.0 %
2005	55.7 %	66.7 %	62.6 %
2006	56.6 %	62.2 %	67.6 %
2007	56.4 %	67.4 %	68.3 %
2008	**58.9 %**	**69.2 %**	**71.2 %**

Figure 24: Container flows per direction and cargo average vessel utilization on the major trade lanes. Source: /UNCTAD Maritime Reviews, Issues 2000 to 2009/.



6.3.1.1 Results of emission factors for ocean going vessels

Table 55 to

Table 57 are examples of emission factors for all vessels used in EcoTransIT World. The first example is based on default values (4 % vessel speed reduction, 80 % main engine load, and average 10.5 tonnes per 1 TEU). The factors in EcoTransIT World are dynamic and vessel speed reduction as well as container load may be modified. Emissions for container vessels are marked yellow. The second and third examples are emission factors for container vessels, normalized to tonne-kilometre and assuming volume cargo and heavy weight cargo.

Vessel types (BC = bulk carrier; CC = container vessel GC = general cargo ship)	Trade and Vesselcategory names	CO_2 SUM g/t-km	CO_2 SECA SUM g/t-km	CO_2 eq SUM g/t-km	CO_2 eq SECA SUM g/t-km	Nox SUM g/t-km	SOx SUM g/t-km	SOx SECA SUM g/t-km	HC SUM g/t-km	PM10 SUM g/t-km	PM10 SECA SUM g/t-km
BC (liquid, dry, and General Cargo)	Suez trade	4.51	4.55	4.56	4.60	0.12	0.07	0.03	0.0045	0.0103	0.0053
BC (liquid, dry, and General Cargo)	Transatlantic trade	6.34	6.40	6.41	6.46	0.17	0.09	0.04	0.0061	0.0140	0.0073
BC (liquid, dry, and General Cargo)	Transpacific trade	5.30	5.34	5.35	5.39	0.14	0.08	0.03	0.0052	0.0119	0.0062
BC (liquid, dry, and General Cargo)	Panama trade	6.34	6.40	6.41	6.46	0.16	0.09	0.04	0.0061	0.0140	0.0073
BC (liquid, dry, and General Cargo)	Other global trade	6.35	6.40	6.41	6.47	0.16	0.09	0.04	0.0061	0.0140	0.0073
BC (liquid, dry, and General Cargo)	Intra-continental trade	8.51	8.58	8.59	8.66	0.22	0.13	0.05	0.0081	0.0186	0.0097
CC	Suez trade	13.58	13.70	13.72	13.84	0.34	0.20	0.08	0.0144	0.0322	0.0168
CC	Transatlantic trade	15.80	15.93	15.95	16.09	0.42	0.24	0.10	0.0165	0.0365	0.0190
CC	Transpacific trade	15.49	15.63	15.65	15.78	0.40	0.23	0.09	0.0162	0.0359	0.0187
CC	Panama trade	15.80	15.93	15.95	16.09	0.42	0.24	0.10	0.0165	0.0365	0.0190
CC	Other global trade	17.15	17.30	17.32	17.47	0.45	0.26	0.11	0.0177	0.0390	0.0204
CC	Intra-continental trade non EU	18.18	18.35	18.37	18.53	0.48	0.27	0.11	0.0186	0.0410	0.0214
CC	Intra-continental trade EU	21.87	22.06	22.09	22.28	0.58	0.33	0.13	0.0218	0.0480	0.0250
CC	EU SECA trade	22.00	N/A	22.22	N/A	0.58	0.13	N/A	0.0207	0.0248	N/A
Great Lakes BC		12.19		12.31		0.31	0.18		0.0115	0.0264	
GC	Coastal	33.97	34.25	34.31	34.59	0.88	0.51	0.20	0.0324	0.0727	0.0375
GC	EU SECA Coastal	34.25	N/A	34.59	N/A	0.87	0.20	N/A	0.0304	0.0372	N/A
BC / GC (dry)	Feeder	16.29	16.42	16.45	16.59	0.40	0.24	0.10	0.0161	0.0358	0.0187
BC / GC (dry)	Handysize	9.69	9.77	9.79	9.87	0.26	0.15	0.06	0.0095	0.0211	0.0111
BC (dry)	Handymax	6.56	6.61	6.62	6.68	0.18	0.10	0.04	0.0065	0.0144	0.0076
BC (dry)	Panamax	4.78	4.82	4.82	4.86	0.13	0.07	0.03	0.0048	0.0107	0.0056
BC (dry)	Aframax	4.23	4.27	4.28	4.31	0.11	0.06	0.03	0.0044	0.0098	0.0052
BC (dry)	Suezmax	3.46	3.49	3.49	3.52	0.09	0.05	0.02	0.0036	0.0080	0.0042
BC (liquid)	Feeder	17.74	17.80	17.91	17.98	0.43	0.26	0.10	10.0586	0.0377	0.0192
BC (liquid)	Handysize	10.58	10.67	10.68	10.78	0.26	0.15	0.06	8.4028	0.0227	0.0115
BC (liquid)	Handymax	7.84	7.91	7.91	7.98	0.20	0.11	0.05	5.3333	0.0172	0.0088
BC (liquid)	Panamax	6.81	6.87	6.87	6.93	0.17	0.10	0.04	3.8135	0.0149	0.0075
BC (liquid)	Aframax	5.06	5.11	5.11	5.16	0.13	0.07	0.03	2.6633	0.0113	0.0058
BC (liquid)	Suezmax	4.35	4.39	4.39	4.43	0.11	0.06	0.03	2.4403	0.0101	0.0053
BC (liquid)	VLCC (+)	2.95	2.98	2.98	3.01	0.08	0.04	0.02	2.3553	0.0070	0.0037
CC	Feeder	26.99	27.22	27.26	27.49	0.70	0.40	0.16	0.0262	0.0579	0.0298
CC	EU SECA Feeder	27.15	N/A	27.42	N/A	0.70	0.16	N/A	0.0250	0.0296	N/A
CC	like Handysize	20.79	20.97	21.00	21.18	0.55	0.31	0.13	0.0208	0.0459	0.0240
CC	EU SECA like Handysize	20.91	N/A	21.12	N/A	0.55	0.13	N/A	0.0198	0.0238	N/A
CC	like Handymax	16.41	16.55	16.57	16.72	0.43	0.25	0.10	0.0171	0.0376	0.0196
CC	like Panamax	15.07	15.20	15.22	15.35	0.40	0.22	0.09	0.0158	0.0351	0.0183
CC	like Aframax	15.21	15.35	15.37	15.50	0.38	0.23	0.09	0.0161	0.0360	0.0188
CC	like Suezmax	11.45	11.55	11.56	11.66	0.28	0.17	0.07	0.0122	0.0273	0.0142
Global average CC	World	15.84	15.98	16.00	16.14	0.41	0.24	0.10	0.0165	0.0365	0.0191

Table 55: Sample of emission factors for marine vessels, assuming 4 % speed reduction, 80 % main engine load and average (10.5 t) container load

Vessel types (BC = bulk carrier; CC = container vessel GC = general cargo ship)	**Trade and Vesselcategory names**	**CO$_2$ SUM g/t-km**	**CO$_2$ SECA SUM g/t-km**	**CO$_2$ eq SUM g/t-km**	**CO$_2$ eq SECA SUM g/t-km**	**Nox SUM g/t-km**	**SOx SUM g/t-km**	**SOx SECA SUM g/t-km**	**HC SUM g/t-km**	**PM10 SUM g/t-km**	**PM10 SECA SUM g/t-km**
CC	Suez trade	23.77	23.98	24.01	24.22	0.60	0.35	0.14	0.0253	0.0564	0.0294
CC	Transatlantic trade	27.64	27.89	27.92	28.16	0.73	0.41	0.17	0.0288	0.0639	0.0333
CC	Transpacific trade	27.11	27.35	27.38	27.62	0.70	0.40	0.17	0.0283	0.0628	0.0328
CC	Panama trade	27.64	27.89	27.92	28.16	0.73	0.41	0.17	0.0288	0.0639	0.0333
CC	Other global trade	30.01	30.27	30.31	30.57	0.79	0.45	0.18	0.0309	0.0683	0.0357
CC	Intra-continental trade non EU	31.82	32.10	32.14	32.42	0.84	0.48	0.20	0.0326	0.0717	0.0375
CC	Intra-continental trade EU	38.27	38.61	38.66	38.99	1.01	0.57	0.23	0.0381	0.0840	0.0438
CC	EU SECA trade	38.50	N/A	38.88	N/A	1.01	0.23	N/A	0.0363	0.0434	N/A
CC	Feeder	47.23	47.64	47.70	48.12	1.23	0.69	0.28	0.0459	0.1014	0.0522
CC	EU SECA Feeder	47.50	N/A	47.98	N/A	1.23	0.28	N/A	0.0437	0.0517	N/A
CC	like Handysize	36.38	36.70	36.75	37.07	0.97	0.54	0.22	0.0365	0.0803	0.0420
CC	EU SECA like Handysize	36.60	N/A	36.96	N/A	0.97	0.22	N/A	0.0347	0.0416	N/A
CC	like Handymax	28.71	28.97	29.00	29.25	0.76	0.43	0.18	0.0299	0.0658	0.0344
CC	like Panamax	26.37	26.60	26.63	26.86	0.70	0.39	0.16	0.0276	0.0615	0.0321
CC	like Aframax	26.62	26.86	26.89	27.12	0.67	0.40	0.16	0.0283	0.0630	0.0329
CC	like Suezmax	20.03	20.21	20.23	20.41	0.50	0.30	0.12	0.0214	0.0477	0.0249
Global average CC	World	27.71	27.96	27.99	28.24	0.72	0.41	0.17	0.0288	0.0639	0.0333

Table 56: Emissions normalized to g/t-km for container vessels and containers carrying volume goods (6 t per TEU).

Vessel types (BC = bulk carrier; CC = container vessel GC = general cargo ship)	Trade and Vesselcategory names	CO$_2$ SUM g/t-km	CO$_2$ SECA SUM g/t-km	CO$_2$ eq SUM g/t-km	CO$_2$ eq SECA SUM g/t-km	Nox SUM g/t-km	SOx SUM g/t-km	SOx SECA SUM g/t-km	HC SUM g/t-km	PM10 SUM g/t-km	PM10 SECA SUM g/t-km
CC	Suez trade	9.84	9.92	9.93	10.02	0.25	0.15	0.06	0.0105	0.0233	0.0122
CC	Transatlantic trade	11.44	11.54	11.55	11.65	0.30	0.17	0.07	0.0119	0.0264	0.0138
CC	Transpacific trade	11.22	11.32	11.33	11.43	0.29	0.17	0.07	0.0117	0.0260	0.0136
CC	Panama trade	11.44	11.54	11.55	11.65	0.30	0.17	0.07	0.0119	0.0264	0.0138
CC	Other global trade	12.42	12.53	12.54	12.65	0.33	0.19	0.08	0.0128	0.0283	0.0148
CC	Intra-continental trade non EU	13.17	13.28	13.30	13.42	0.35	0.20	0.08	0.0135	0.0297	0.0155
CC	Intra-continental trade EU	15.84	15.98	16.00	16.14	0.42	0.24	0.10	0.0158	0.0348	0.0181
CC	EU SECA trade	15.93	N/A	16.09	N/A	0.42	0.10	N/A	0.0150	0.0180	N/A
CC	Feeder	19.54	19.71	19.74	19.91	0.51	0.29	0.11	0.0190	0.0419	0.0216
CC	EU SECA Feeder	19.66	N/A	19.85	N/A	0.51	0.11	N/A	0.0181	0.0214	N/A
CC	like Handysize	15.06	15.19	15.21	15.34	0.40	0.23	0.09	0.0151	0.0332	0.0174
CC	EU SECA like Handysize	15.14	N/A	15.29	N/A	0.40	0.09	N/A	0.0144	0.0172	N/A
CC	like Handymax	11.88	11.99	12.00	12.11	0.31	0.18	0.07	0.0124	0.0272	0.0142
CC	like Panamax	10.91	11.01	11.02	11.12	0.29	0.16	0.07	0.0114	0.0254	0.0133
CC	like Aframax	11.02	11.11	11.13	11.22	0.28	0.16	0.07	0.0117	0.0261	0.0136
CC	like Suezmax	8.29	8.36	8.37	8.45	0.21	0.12	0.05	0.0089	0.0197	0.0103
Global average CC	World	11.47	11.57	11.58	11.68	0.30	0.17	0.07	0.0119	0.0265	0.0138

Table 57: Emissions normalized to g/t-km for container vessels and containers carrying heavy goods (14.5 t per TEU).

6.3.1.2 The modelling of reduced vessel speed in EcoTransIT World

The default emission factors in EcoTransIT World are based on 4 % reduced vessel speeds and 80 % main engine load. The design speed of a vessel, which is reached at approximately 90 % main engine load, is considered 100 % or full speed. In the expert mode, users may alter the service speed of the vessels up to 30 % below design speed. This feature reflects the option of lowing greenhouse gas emissions effectively by lowering the vessel speed (slow steaming). The effect is due to the potentiated decline of required engine power in relation to reductions in vessel speed. Speeds below 30-40 % below design speed are not recommended by OEM for a longer period of time without adjusting engine and lubrication parameters.

The propeller rotation of a vessel is not converted at as one to one ratio into forward movement. Due to several factors of resistance, the propeller slips in the water, thus increasing the power demand on the propeller shaft. Resisting forces that counter the forward pulling force include wind, wave, friction and eddy resistance. All but the friction resistance increase over-proportionally with increased vessel speed /MAN 2006/

The slip effect of a propeller in relation to the speed (or revolutions of the propeller) is described in the propeller law. The propeller law states that the resistance with higher ship speeds is proportional to the square of the vessel's speed ($R = c * V^2$ with c = a constant). The necessary power requirement is related to the ship resistance R and its speed V. Thus the effect of vessel speed on required propulsion power is in proportional to the power of 3.

$$P = R \times V = c \times V^3$$

MAN /2006/ states that with high speed vessels such as container ships, empirical data indicates a relationship to the power of 4.5 and for bulk carriers of 3.5. However, the effects of slow steaming are countered by hull and propeller fouling as well as ocean currents and heavy weather conditions. Thus, for EcoTransIT World the power relation of 3 was chosen for all vessels as a more conservative approach.

Since the speed reduction only affects the main engine during the voyage at sea the theoretical standard year is used as a baseline. The user may choose a reduction in speed in percent of the average cruise speed of this vessel category. The engine load and respectively the emissions are reduced by applying the propeller law. For bulk vessels the formula is:

$$MEloi = (Vi / Vn)^3$$

With MEloi as the main engine load on trip (i), Vi the reduced speed on trip (i) and Vn the average cruise speed in this class.

At the same time the cargo carrying capacity is linearly reduced and the operating hours of auxiliary engines at sea are linearly increased to the percent of the speed reduction during the sea voyage. The time in port remains unchanged. Thus, starting from the standard year, the theoretical time for carrying a given amount of cargo increases. The linear reduction in vessel carrying capacity during the sea voyage is recognized in the calculation. As a consequence, behind the aggregated emission factor for a vessel, normalized to one tonne-kilometre are three separate emission factors that behave differently with vessel speed reduction:

- Emissions from main engine at sea: reduction applying the propeller law
- Emissions from auxiliary engines at sea: increase linear to slower speed
- Emissions from auxiliary engines in port: steady.

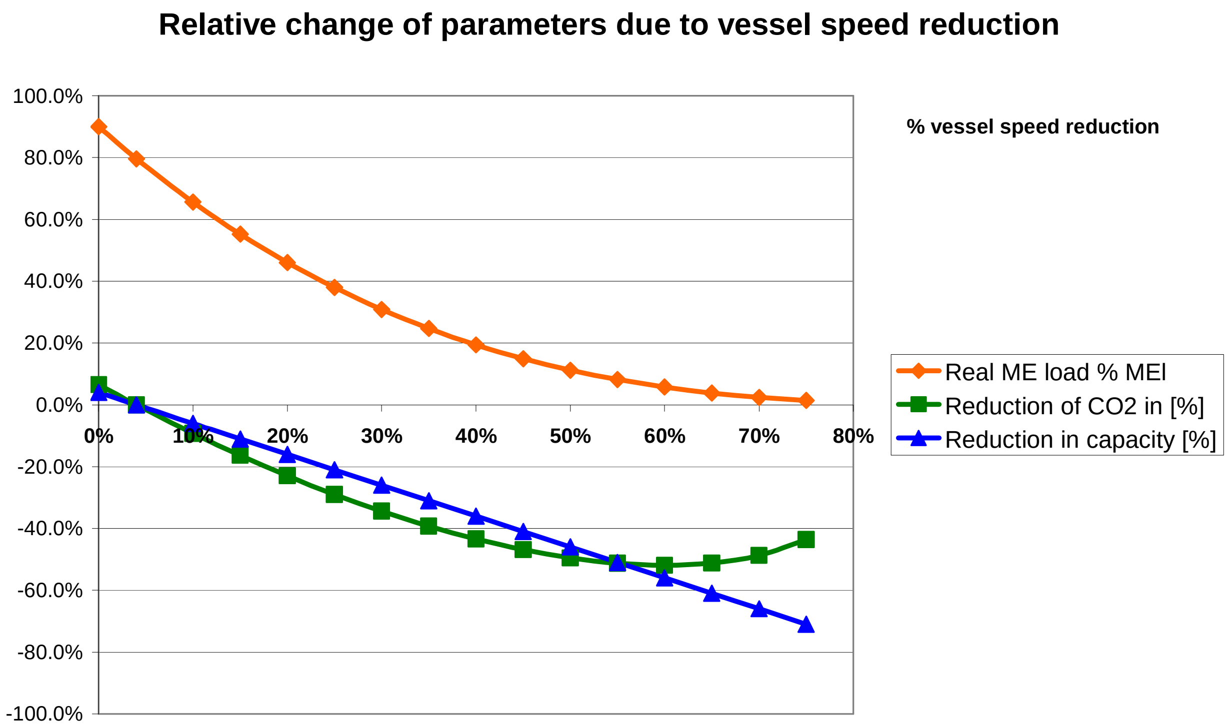
The formula is:

$$Ef = (((MEs \times \frac{MEloi}{MElon}) \times \frac{1}{(1-\%g\,\mathrm{Re}d)}) + (AUXs \times \frac{1}{(1-\%g\,\mathrm{Re}d)}) + AUXp) \times \frac{Ufn}{Ufc}$$

With:

Ef = effective emission factor in g/t-km; MEs = emission factor main engine at sea; MEloi = main engine load at sea for trip (i); Melon = nominal main engine load (90%); red% = percent vessel speed reduction; AUXs = emission factor from auxiliary engines at sea; AUXp = emission factor from auxiliary engines in port, normalized to t-km; Ufn = default vessel utilization factor; Ufc = customized vessel utilization factor.

Figure 25: Relative change of parameters with reduced vessel speed.



Vessel types (BC = bulk carrier; CC = container vessel GC = general cargo ship)	Trade and Vesselcategory names	CO_2 SUM g/t-km	CO_2 SECA SUM g/t-km	CO_2 eq SUM g/t-km	CO_2 eq SECA SUM g/t-km	Nox SUM g/t-km	SOx SUM g/t-km	SOx SECA SUM g/t-km	HC SUM g/t-km	PM10 SUM g/t-km	PM10 SECA SUM g/t-km
BC (liquid, dry, and General Cargo)	Suez trade	3.64	3.68	3.68	3.71	0.09	0.05	0.02	0.0036	0.0082	0.0043
BC (liquid, dry, and General Cargo)	Transatlantic trade	5.15	5.20	5.20	5.25	0.13	0.08	0.03	0.0049	0.0113	0.0058
BC (liquid, dry, and General Cargo)	Transpacific trade	4.29	4.33	4.33	4.37	0.11	0.06	0.03	0.0041	0.0095	0.0049
BC (liquid, dry, and General Cargo)	Panama trade	5.15	5.20	5.21	5.25	0.13	0.08	0.03	0.0049	0.0113	0.0058
BC (liquid, dry, and General Cargo)	Other global trade	5.16	5.20	5.21	5.25	0.13	0.08	0.03	0.0049	0.0113	0.0058
BC (liquid, dry, and General Cargo)	Intra-continental trade	6.93	6.99	7.00	7.06	0.18	0.10	0.04	0.0065	0.0150	0.0078
CC	Suez trade	7.99	8.06	8.07	8.14	0.20	0.12	0.05	0.0085	0.0188	0.0098
CC	Transatlantic trade	9.37	9.45	9.46	9.54	0.24	0.14	0.06	0.0097	0.0214	0.0112
CC	Transpacific trade	9.16	9.24	9.25	9.34	0.24	0.14	0.06	0.0095	0.0210	0.0109
CC	Panama trade	9.37	9.45	9.46	9.54	0.24	0.14	0.06	0.0097	0.0214	0.0112
CC	Other global trade	10.18	10.27	10.28	10.37	0.27	0.15	0.06	0.0105	0.0230	0.0120
CC	Intra-continental trade non EU	10.84	10.94	10.95	11.05	0.28	0.16	0.07	0.0111	0.0242	0.0126
CC	Intra-continental trade EU	13.06	13.17	13.19	13.30	0.34	0.19	0.08	0.0130	0.0284	0.0148
CC	EU SECA trade	13.13	N/A	13.26	N/A	0.34	0.08	N/A	0.0123	0.0146	N/A
Great Lakes BC		9.93		10.03		0.25	0.15		0.0092	0.0214	
GC	Coastal	27.79	28.02	28.07	28.30	0.71	0.41	0.16	0.0264	0.0591	0.0303
GC	EU SECA Coastal	28.02	N/A	28.30	N/A	0.71	0.16	N/A	0.0247	0.0299	N/A
BC / GC (dry)	Feeder	13.24	13.36	13.38	13.49	0.32	0.20	0.08	0.0131	0.0289	0.0151
BC / GC (dry)	Handysize	7.85	7.91	7.93	7.99	0.21	0.12	0.05	0.0077	0.0170	0.0089
BC (dry)	Handymax	5.28	5.33	5.34	5.38	0.14	0.08	0.03	0.0052	0.0116	0.0061
BC (dry)	Panamax	3.85	3.88	3.89	3.92	0.10	0.06	0.02	0.0039	0.0086	0.0045
BC (dry)	Aframax	3.39	3.42	3.42	3.45	0.08	0.05	0.02	0.0035	0.0078	0.0041
BC (dry)	Suezmax	2.76	2.78	2.79	2.81	0.07	0.04	0.02	0.0029	0.0064	0.0034
BC (liquid)	Feeder	14.64	14.69	14.78	14.84	0.35	0.21	0.08	11.3551	0.0307	0.0155
BC (liquid)	Handysize	8.80	8.88	8.89	8.97	0.22	0.13	0.05	9.4872	0.0186	0.0093
BC (liquid)	Handymax	6.44	6.50	6.51	6.56	0.16	0.09	0.04	6.0211	0.0140	0.0071
BC (liquid)	Panamax	5.63	5.68	5.68	5.73	0.14	0.08	0.03	4.3049	0.0121	0.0061
BC (liquid)	Aframax	4.10	4.14	4.15	4.18	0.11	0.06	0.02	3.0063	0.0091	0.0047
BC (liquid)	Suezmax	3.51	3.54	3.55	3.58	0.09	0.05	0.02	2.7546	0.0081	0.0042
BC (liquid)	VLCC (+)	2.36	2.39	2.39	2.41	0.06	0.04	0.01	2.2886	0.0056	0.0029
CC	Feeder	16.28	16.42	16.44	16.58	0.42	0.24	0.09	0.0158	0.0345	0.0177
CC	EU SECA Feeder	16.37	N/A	16.54	N/A	0.42	0.09	N/A	0.0149	0.0174	N/A
CC	like Handysize	12.38	12.49	12.50	12.61	0.33	0.18	0.08	0.0124	0.0271	0.0141
CC	EU SECA like Handysize	12.45	N/A	12.57	N/A	0.33	0.08	N/A	0.0117	0.0140	N/A
CC	like Handymax	9.80	9.88	9.90	9.98	0.26	0.15	0.06	0.0102	0.0222	0.0116
CC	like Panamax	8.85	8.93	8.94	9.02	0.23	0.13	0.05	0.0092	0.0205	0.0106
CC	like Aframax	8.95	9.02	9.03	9.11	0.22	0.13	0.05	0.0094	0.0210	0.0109
CC	like Suezmax	6.74	6.80	6.81	6.87	0.17	0.10	0.04	0.0072	0.0159	0.0083
Global average CC	World	9.38	9.46	9.47	9.55	0.24	0.14	0.06	0.0097	0.0214	0.0111

Table 58: Sample of emission factors for marine vessels, assuming 15 % speed reduction, resulting in approximately 55 % main engine load and average (10.5 t) container load

6.4 Detailed data of different types of aircrafts

Table 59 Design range, payload and seats of different types of aircrafts

Type	Aircraft Code	Type of Aircraft	Design Range [km]	Max. Pay-load [t]	Typical Seats [number]
Freighter	BA46F	British Aerospace BAe 146-300QTF	1,930	12.5	
Freighter	DC93F	McDonnell Douglas DC-9-30F	1,324	16.3	
Freighter	B732F	Boeing 737-200C (Advanced)	2,240	17.3	
Freighter	T154F	Tupolew Tu-154S	2,500	18.0	
Freighter	B737F	Boeing 737-700C	5,335	18.8	
Freighter	B722F	Boeing 727-200F	2,570	29.5	
Freighter	B752F	Boeing 757-200F	5,830	32.8	
Freighter	A310F	Airbus 310-200F	5,560	39.1	
Freighter	A300F	Airbus 300-600F	4,850	48.1	
Freighter	DC87F	McDonnell Douglas DC-8-73F	5,186	48.8	
Freighter	B763F	Boeing 767-300F	6,025	53.7	
Freighter	DC10F	McDonnell Douglas DC-10-30F	5,867	76.4	
Freighter	MD11F	McDonnell Douglas MD-11	6,700	89.6	
Freighter	B742F	Boeing 747-200F	6,640	110.0	
Freighter	B744F	Boeing 747-400F	8,230	112.6	
Belly	DC93	McDonnell Douglas DC-9-30	2,631		80
Belly	B731	Boeing 737-100	2,850	1.5	85
Belly	F100	Fokker 100	3,170	1.0	85
Belly	MD81-88	McDonnell Douglas M81-M88	3,798		155
Belly	B734	Boeing 737-400	4,005	1.8	146
Belly	B722	Boeing 727-200	4,420	1.5	147
Belly	A320	Airbus A320-200	5,700	2.0	150
Belly	A310	Airbus A310-200	6,800		240
Belly	B752	Boeing 757-200	7,222	4.0	200
Belly	B772	Boeing 777-200	9,695	26.6	305
Belly	DC10	McDonnell Douglas DC10-30	10,010		250
Belly	B763	Boeing 767-300 ER	11,070	12.0	218
Belly	A330	Airbus A330-200	12,500	24.0	253
Belly	B742	Boeing 747-200	12,700	15.0	366
Belly	B744	Boeing 747-400	13,450	14.0	416
Belly	A340	Airbus A340-300	13,700	23.0	295

6.5 Upstream processes– additional information

Table 60 Energy split of electricity consumption used by railways

Region	Code	Source	Reference Year	Solid fuels	Oil	Gas	Nuclear	Renewable	Other
Africa	*default*	/IEA 2007a/	2006	42.4%	9.9%	27.9%	2.0%	17.9%	0.0%
	ZA	/IEA 2007a/	2006	92.6%	0.0%	0.0%	4.7%	2.7%	0.0%
Asia and Pacific	*default*	/IEA 2007a/	2006	45.2%	9.4%	24.2%	3.6%	17.2%	0.4%
	CN	/IEA 2007a/	2006	79.4%	1.8%	0.2%	1.9%	16.4%	0.3%
	HK	/IEA 2007a/	2006	68.0%	0.3%	31.7%	0.0%	0.0%	0.0%
	IN	/IEA 2007a/	2006	67.2%	4.2%	8.3%	2.5%	17.5%	0.3%
	JP	/IEA 2007a/	2006	26.6%	10.7%	20.6%	27.5%	10.9%	3.6%
	KR	/IEA 2007a/	2006	37.3%	5.8%	15.8%	37.0%	1.5%	2.6%
Australia	*default*	/IEA 2007a/	2006	35.8%	8.0%	18.3%	25.1%	9.8%	3.0%
	AU	/IEA 2007a/	2006	78.3%	0.9%	11.7%	0.0%	8.3%	0.8%
Central and South America	*default*	/IEA 2007a/	2006	3.0%	10.5%	12.2%	2.2%	71.7%	0.5%
	BR	/IEA 2007a/	2006	2.3%	2.8%	3.4%	3.1%	87.5%	0.8%
Europe	eur	/IEA 2007a/	2006	42.6%	5.7%	7.9%	14.8%	28.7%	0.3%
	AT	/UIC 2009/	2007	0.0%	0.0%	0.0%	0.0%	89.2%	10.8%
	BE	/UIC 2009/	2007	13.6%	0.0%	16.6%	57.9%	2.1%	9.7%
	BG	/UIC 2009/	2007	56.7%	1.0%	3.9%	29.2%	9.2%	0.0%
	CY	/Eurostat 2009/	2007	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
	CZ	/UIC 2009/	2007	57.3%	0.0%	0.0%	40.7%	2.0%	0.0%
	DK	/UIC 2009/	2007	49.4%	2.7%	17.5%	0.0%	26.0%	4.4%
	EE	/Eurostat 2009/	2007	93.4%	0.3%	5.0%	0.0%	1.3%	0.0%
	FI	/UIC 2009/	2007	0.0%	0.0%	0.0%	26.3%	32.4%	41.3%
	FR	/UIC 2009/	2005	4.0%	1.8%	3.3%	85.6%	4.9%	0.4%
	DE	/UIC 2009/	2007	46.0%	0.0%	8.8%	29.9%	14.0%	1.4%
	GR	/Eurostat 2009/	2007	53.8%	15.0%	22.3%	0.0%	9.0%	0.0%
	HU	/UIC 2009/	2007	18.0%	1.5%	38.7%	36.5%	4.6%	0.7%
	IS	/Eurostat 2009/	2006	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
	IE	/Eurostat 2009/	2007	26.3%	6.8%	55.4%	0.0%	11.5%	0.0%
	IL	/IEA 2007a/	2006	68.8%	13.0%	18.2%	0.0%	0.1%	0.0%
	IT	/UIC 2009/	2007	29.8%	15.7%	0.0%	0.0%	29.3%	25.2%
	LV	/Eurostat 2009/	2007	0.0%	0.3%	39.7%	0.0%	60.0%	0.0%
	LT	/Eurostat 2009/	2007	0.1%	2.8%	17.4%	69.6%	8.3%	1.7%
	LU	/Eurostat 2009/	2007	0.0%	0.0%	71.9%	0.0%	28.1%	0.0%
	MT	/Eurostat 2009/	2007	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
	NL	/UIC 2009/	2005	23.3%	0.0%	51.8%	9.1%	9.7%	6.1%
	NO	/UIC 2009/	2007	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
	PL	/UIC 2009/	2005	93.7%	0.0%	1.9%	0.0%	0.0%	4.4%
	PT	/Eurostat 2009/	2007	25.3%	10.0%	28.0%	0.0%	36.7%	0.0%
	RO	/UIC 2009/	2007	40.5%	1.1%	17.7%	13.0%	26.9%	0.9%
	SK	/UIC 2009/	2007	14.2%	0.0%	0.0%	66.0%	19.8%	0.0%
	SI	/UIC 2009/	2007	48.2%	1.0%	6.2%	30.0%	13.6%	1.0%
	ES	/UIC 2009/	2007	25.1%	0.8%	24.7%	19.5%	29.1%	0.8%
	SE	/UIC 2009/	2007	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
	CH	/UIC 2009/	2007	0.0%	0.0%	0.0%	26.5%	73.5%	0.0%
	TR	/Eurostat 2009/	2007	26.4%	3.3%	50.0%	0.0%	19.7%	0.6%
	UK	/UIC 2009/	2007	33.1%	1.0%	43.7%	14.9%	5.3%	2.1%
North America	*default*	/IEA 2007a/	2006	16.3%	1.5%	5.4%	15.5%	61.3%	0.0%
	US	/IEA 2007a/	2006	48.6%	1.8%	19.8%	19.0%	10.0%	0.8%
Russia and FSU	*default*	/IEA 2007a/	2006	20.3%	2.9%	40.1%	17.5%	17.7%	1.5%
	RU	/IEA 2007a/	2006	17.3%	2.4%	44.6%	15.5%	18.3%	1.9%

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8 Expressions, Abbreviations and conversion factors

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 EcoTransIT World 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
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	
TEU	Twenty foot equivalent	Unit for container transport

Energy conversion factors

1 kg Diesel/MDO/MGO	42.’96 MJ
1 kg HFO	40.34 MJ
1kWh	3,6 MJ
Source: AG Energiebilanzern	