ifeu -
Institut für Energie-
und Umweltforschung
Heidelberg GmbH

EcoPassenger

Environmental Methodology and Data

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Contents

Contact:

Wolfram Knörr

ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH

Wilckensstr. 3, D-69120 Heidelberg, Germany

Tel. +49-6221-4767-0 (Zentrale), -37 (direkt), -19 (Fax)

e-mail: wolfram.knoerr@ifeu.de - homepage: http://www.ifeu.de

1 System boundaries and basic definitions

1.1 Environmental impacts

Transportation has various impacts on the environment. These have been mainly 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. Resources 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 passenger transport has impacts within all these categories. However, only for some of these categories is it possible to make a comparison of individual transports on a quantitative basis. In this version of EcoPassenger therefore the selection of environmental performance values had to be limited to a few but important parameters. The selection was done according to the following criteria:

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

The following parameters for environmental impacts of transports were selected:

Table 1 Environmental impacts included in EcoPasssenger

Abbr.	Description	Reasons for inclusion
PEC	Primary energy consumption	Main indicator for resource consumption
CO_2	Carbon dioxide emissions	Main indicator for greenhouse effect
NOx	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
NMHC	Non-methane hydro carbons	Human toxicity, summer smog
PM	Exhaust particulate matter from vehicles (combustion), mainly PM 2.5 and from energy production and provision (combustion power plants, refineries, sea transport of primary energy carriers), composition: all particle sizes, about 80% PM 2.5, 90% PM 10 (by mass)	Human toxicity, summer smog

Thus the categories **land use**, **noise** and **depletion of the ozone layer** were not taken into consideration. For electricity driven rail transport the risks of nuclear power generation from radiation and waste disposal are also not considered.

Furthermore the greenhouse gases **methane and nitrous oxide** are also not included in the current version. This is due to the fact that CO_2 is the dominant greenhouse gas in the transport sector and methane emissions are therefore only of minor importance. **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 distances have additional climatic impacts. Regarding eco-toxicity and human toxicity on the other hand, the location of the emission source is highly relevant:

Particulate emissions from power plants and from engine combustion might have different impacts (due to different particle sizes and possibly also their composition) but it cannot be ruled out that they might also have the same impact. The knowledge about health effects is still uncertain and the data base given does not allow a further differentiation. Yet at least it can be ascertained that particulates resulting from combustion of diesel fuel have adverse health impacts.

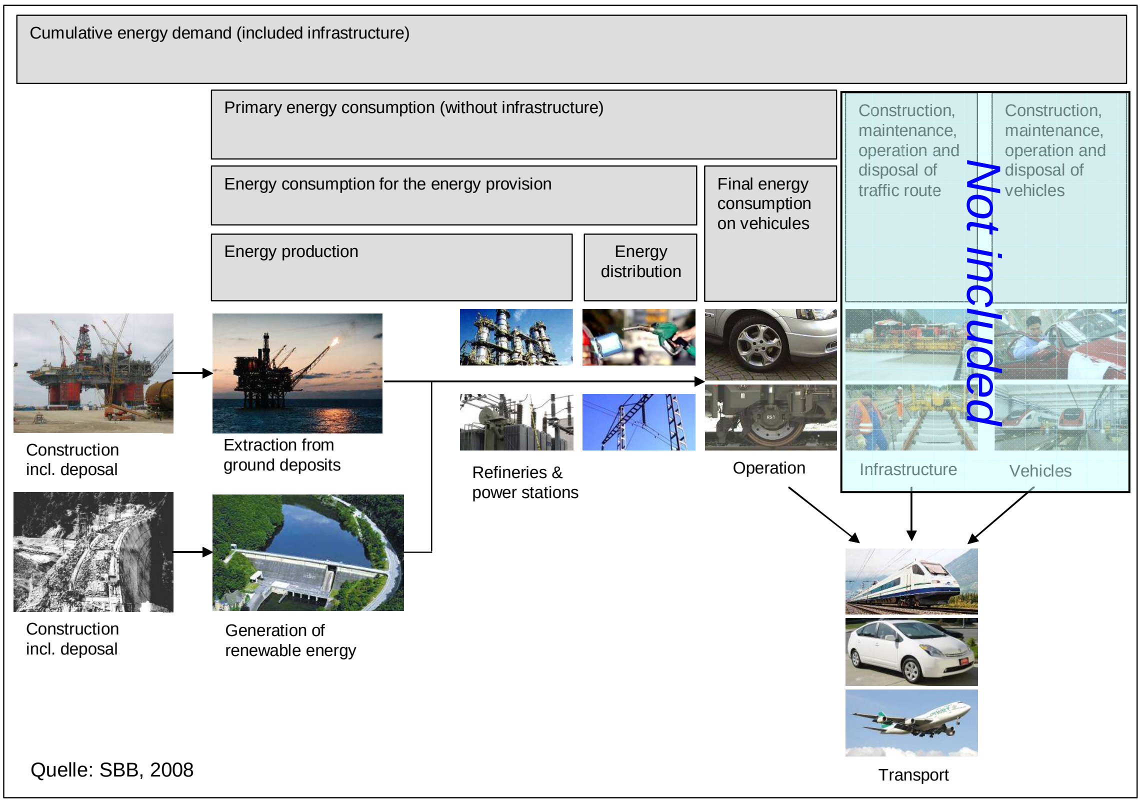
System boundaries

In EcoPassenger, only those environmental impacts are considered which are linked to the operation of vehicles and to fuel production. Not included are therefore:

- the production and maintenance of vehicles
- the construction and maintenance of transport infrastructure
- additional resource consumption like administration buildings, stations, airports, etc..

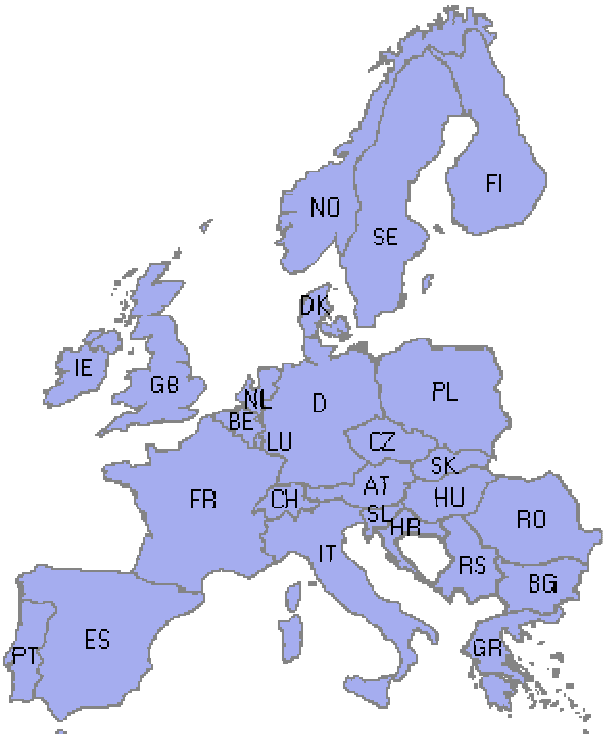
All emissions directly caused by **the operation** of vehicles and the final energy consumption are taken into account. Additionally, **all** emissions and the energy consumption of the **generation of final energy (fuels, electricity)** are included. The following figure shows an overview of the system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

Figure 1 System boundaries



1.2 Spatial differentiation

In EcoPassenger most of the EU countries with railway lines are considered.



The environmental impacts of the different transport modes partly differ between the countries. Significant influencing factors are the types of vehicles used, and the type of energy carriers and conversion used. Wide differences result particularly from the method and national mix of electricity production.

Less pronounced are the differences in end energy consumption of similar vehicles in different countries. Thus in all countries usually passenger cars of different international manufacturers are used following the same registration approval rules. For air transport, the existing vehicles are likewise used internationally.

Bigger differences could instead exist for railway transport, where the various railway companies employ different railcars, locomotives and train configurations and buy energy from different sources. To include this differences, statistical data from the Railenergy project /UIC 2007/ and uptdated energy values /UIC 2009/ are used. This data are officially provided by the European railway companies via the International Union of Railways (UIC).

Thus the data are differentiated according to the following spatial criteria:

Country specific values: railways mix of electricity production, load factors and specific energy consumption per train type (if available), the sulphur content of diesel fuel and the share of biofuels (if available).

Common data: emission factors and specific energy consumption for passenger cars, bus and air transport.

1.3 Transport modes and propulsion systems

Passenger transport in Europe is performed by different transport modes. Within the EcoPassenger 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	Propulsion energy
Road	Passenger Cars	Gasoline, Diesel, LPG, Hybrid
Rail	Rail transport with Highspeed, Intercity, Regional and Suburban Trains	Electricity and diesel fuel
Aircraft transport	Air planes	Kerosene
Feeder	Busses, Metro, Taxis	Diesel, Electricity

For several relations **ferries** are part of the journey. In this version of EcoPassenger it was not possible to estimate the energy consumption and emissions for ferries because the timetable data of Merits (see the following section) did not allow to identify ferries as separate transport mode. Thus the distance for the ferry transport with train and car is considered, but no separate energy and emission values.

1.4 Routing

The aim of the integrated route planner is to find real routes for journeys in Europe based on existing train and flight connections and car routes for an ecological comparison of the different modes.

1.4.1 Data Basis

The HAFAS route planner uses “Merits” train timetable data (UIC), a database with European flight relations with up to two legs (www.flugplan.de) and PTV xServer components using Navteq data for car routing to find different routes for travelling from A to B.

1.4.2 Length of a Route

The length of the different routes is essential for the calculation of the different energy and emission values. Due to different emission data tables for different countries the route length of international journey has to be break down to single route lengths in different countries.

The length of the **car routes** in Ecopassenger is the result of the industry standard car routing component and is equivalent to most car routing systems.

The length of the **train routes** is determined by the polygon defined by all in-between stops of a train. The length of the train route between two connected stations is calculated by the line of sight distance which is extended by 20%-30% *depending on cases.* The advantage of this EcoPassenger methodology compared to “default” pure rail network routing comes from the use of timetable data for the routing calculation, the real routes used for passenger travels can differ from the default geographical shortest route, and it varies on different kind of train services.

Every country has an own table concerning emission data of cars and trains. Every section of an international journey is assigned to a certain country by flags in the routing data or UIC codes of passed by stations. If a train route contains explicitly a border stop, the route is divided at this border. If there is no border stop but the UIC code of two consecutive stops changes, the route section between these stops is simply cut into halves and every half is assigned two one of the both countries.

The emissions of a train depend on the type of traction. The system holds the data, if a station can only be reached by Diesel trains. This data is extracted from the EcoTransit system, which has collected this data for the whole railway network in Europe /IFEU 2008a/. If a train passes a station which can only be reached by Diesel traction it is presumed, that the whole train runs with Diesel traction. Otherwise electric traction is assumed.

Ferries do not have a special treatment because of a lack of reliable emission data. They will be handled as a car or train route instead based on the distance of the different harbours.

Flights are calculated with the air-line distance. For deviations from the air-line distance, depending from air routes or wait loops an average distance of 50 km is added. A flight journey needs public transport or private car to reach the airports. The length of the route is estimated by the “line of sight” for public transport added by 30% or the result of car routing component for the use of the car. The country of the airports locations defines which country emission data table is used for the whole airport transfer. For distances over 100 km IC trains are assumed, for less than 100 km regional trains.

The search for flights considers all airports in a radius of 250 km of the journey origin and destination. If several flight connections are possible the system searches for the shortest route and values the length of the airport transfer twice for the selection of shortest route.

The EcoPassenger system has no access to flight timetable data for an online routing. But the possible flight relations (including 1-stop flights) are determined based on real flight data. A flight relation between two airports was added to the system, if there is at least one flight per week available. The system considers all direct flight connections and 1-stop flight connections, if the total flight distance does not exceed the line of sight distance between start and destination by 100%.

The travel times for flight journeys are estimated with average values for the travel times between the airports and the average travel times for the feeder. Feeder times are estimated with an average speed of 70 km/h for feeder distances below 100 km and 100 km/h for longer distances. For the transfer on the airports 75 minutes are added in total.

2 Energy and emission data

2.1 Energy supply

The main energy carriers used in passenger transport are gasoline, diesel, LPG and electricity. To compare the environmental impacts of transport processes with different energy carriers, the total energy chain has to be considered:

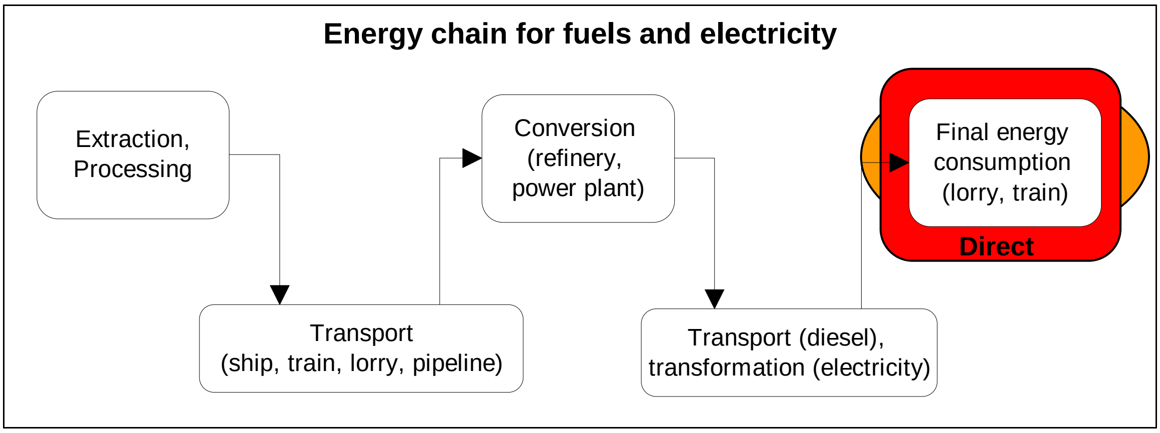
Energy chain of electricity production:

- 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 cable losses).

Energy chain of fuel production:

- Exploration and extraction of primary energy (crude oil, gas) and transport to the entrance of the refinery.
- Conversion within the refinery (including construction and deposal of refineries).
- Energy distribution (transport to petrol station, filling losses).

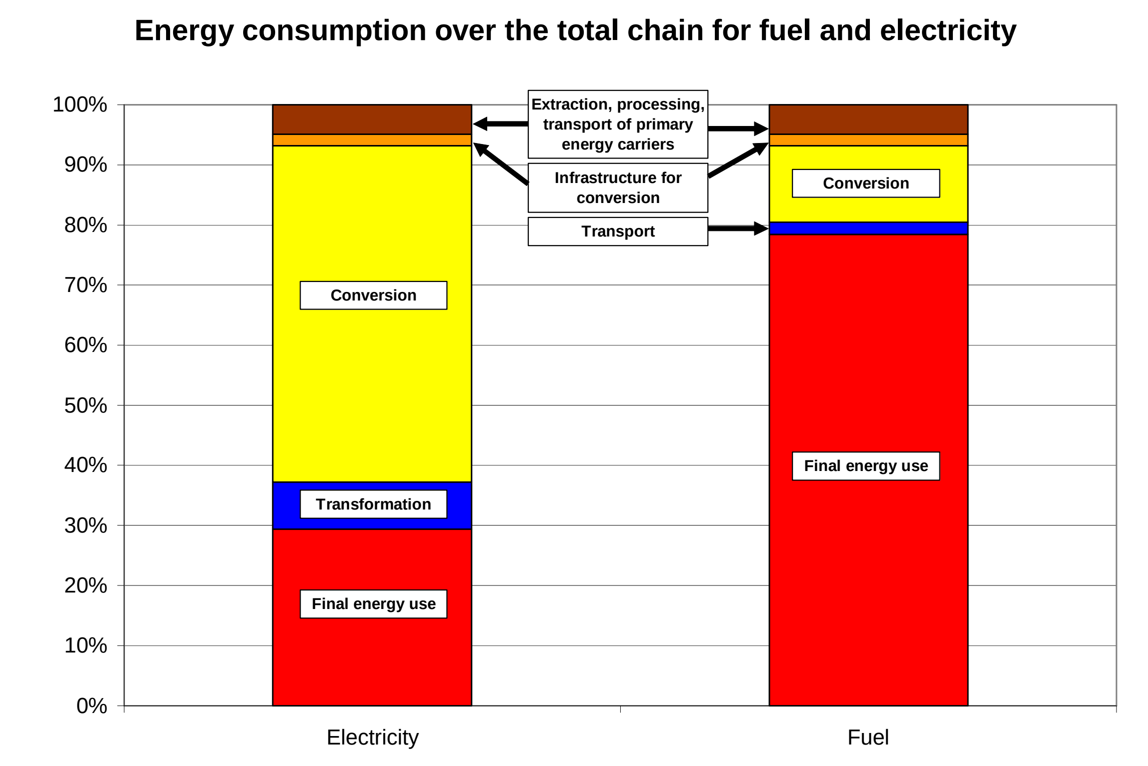
Figure 2 Energy chain for diesel fuel and electricity



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

The energy consumption over the total energy chain depends on the efficiency of the individual steps of the chain. The following figure shows schematically the contribution of each step of energy production and consumption. If electricity is used, about 2/3 (depending on the input mix) of the energy consumption are required for conversion and the upstream process steps, whereas for diesel fuel, the final energy use contributes about 78 % of the total primary energy demand.

Figure 3 Energy chain for fuel and electricity



Note: Schematic presentation by IFEU

2.1.1 Exploration, extraction, transport and production of fuels

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 2006/ The following table shows the specific figures for the emissions and the energy consumption for the prechain.

Table 3 Emission factors and energy efficiency of fossil fuels for energy production

	Efficiency*	CO2	NOx	SO2	NMVOC	PM
		kg	g	g	g	g
Gasoline	75%	0.67	2.1	5.8	2.1	0.29
Diesel	78%	0.47	1.8	4.4	1.5	0.23
Kerosene	79%	0.45	1.8	4.3	1.5	0.23
LPG	83%	0.55	1.8	4.9	1.5	0.24
Marine Diesel Oil	79%	0.40	1.7	4.0	1.5	0.21
Efficiency: Relation final energy/primary energy ; emission factors related to final energy (kg fuel) Source. Ecoinvent 2009						

2.1.2 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 real life, be traced to a particular power plant. Special properties of electricity have to be considered:

- Each country in Europe 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. For the allocation of the environmental impacts of CHP different methodologies are proposed. (described e. g. in /Ecoinvent 2003/). Currently we use the allocation based on the energy content of electricity and heat. This allocation methodology does not take into account the different exergy contents of the two products heat and power into estimation. So electricity and heat are treated like equivalent products. The efficiency of CHP-power plants is assessed with 80% for all countries /Ecoinvent 2003/. Compared with other allocation methodologies (e. g. exergy content), due to energy content allocation, the electricity production gets a relatively high benefit.

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 UIC Energy Database /UIC 2009/. If no values are available, data from EU-statistics /Eurostat 2009/ and other sources (see table next page) are used. The data for CHP are taken from /Eurelectric 2007/ (share of electricity generation in CHP produced thermal on conventional thermal electricity production). The following table shows the values used.

Table 4 Energy split of electricity consumption used by railways in 2007*

Country	Source	Solid fuels	Oil	Gas	Nuclear	Renewables	Other
AT	/UIC 2009/	0,00%	0,00%	0,00%	0,00%	89,65%	10,35%
BE	/UIC 2009/	13,63%	0,00%	16,56%	57,95%	2,11%	9,74%
BG	/UIC 2009/	56,73%	0,99%	3,91%	29,15%	9,22%	0,00%
CH	/UIC 2009/	0,00%	0,00%	0,00%	26,47%	73,53%	0,00%
CZ	/UIC 2009/	57,31%	0,00%	0,00%	40,65%	2,04%	0,00%
DE	/UIC 2009/	45,95%	0,00%	8,78%	29,86%	14,02%	1,40%
DK	/UIC 2009/	49,42%	2,69%	17,47%	0,00%	26,24%	4,18%
ES	/UIC 2009/	25,07%	0,78%	24,73%	19,50%	29,91%	0,00%
FI	/UIC 2009/	0,00%	0,00%	0,00%	26,35%	33,86%	39,79%
FR	/UIC 2009/	4,02%	1,76%	3,27%	85,65%	4,91%	0,39%
GR	/Eurostat 2009/	53,76%	14,95%	22,28%	0,00%	9,01%	0,00%
HR	/UIC 2009/	10,47%	21,81%	0,00%	31,60%	36,12%	0,00%
HU	/UIC 2009/	17,97%	1,46%	38,72%	36,52%	4,64%	0,68%
IE	/Eurostat 2009/	26,33%	6,81%	55,37%	0,00%	11,50%	0,00%
IT	/UIC 2009/	28,10%	7,21%	35,17%	0,00%	29,50%	0,03%
LU	/Eurostat 2009/	0,00%	0,00%	71,91%	0,00%	28,09%	0,00%
ME	/IEA 2007/	67,23%	0,87%	0,19%	0,00%	31,57%	0,13%
NL	/UIC 2009/	23,31%	0,00%	51,79%	9,11%	9,76%	6,02%
NO	/UIC 2009/	0,00%	0,00%	0,00%	0,00%	100,00%	0,00%
PL	/UIC 2009/	93,70%	0,00%	1,91%	0,00%	0,00%	4,40%
PT	/Eurostat 2009/	25,33%	9,95%	27,98%	0,00%	36,74%	0,00%
RO	/UIC 2009/	40,52%	1,08%	17,66%	12,97%	26,92%	0,86%
RS	/IEA 2007/	67,23%	0,87%	0,19%	0,00%	31,57%	0,13%
SE	/UIC 2009/	0,00%	0,00%	0,00%	0,00%	100,00%	0,00%
SI	/UIC 2009/	48,17%	0,98%	6,15%	30,05%	13,66%	0,98%
SK	/UIC 2009/	26,02%	0,00%	4,44%	57,78%	11,77%	0,00%
UK	/UIC 2009/	33,09%	0,97%	43,66%	14,87%	5,95%	1,46%

*except Serbia and Montenegro (Reference year 2006)
UIC 2009: railway mix, other sources: national mix

Table 5 Energy efficiency and emission factors of the electricity supply for railway transport in European countries 2007*

Country	Share CHP**	Efficiency	CO2	NOx	SO2	NMVOC	PM10
	[%]	[%]	kg/kWh	g/kWh	g/kWh	g/kWh	g/kWh
AT	27%	78%	0,112	0,094	0,079	0,007	0,024
BE	8%	26%	0,371	0,749	1,296	0,054	0,102
BG	8%	30%	0,588	1,295	1,896	0,071	0,140
CH	1%	54%	0,005	0,019	0,012	0,004	0,012
CZ	23%	32%	0,612	0,970	1,155	0,018	0,054
DE	13%	33%	0,508	0,472	0,407	0,053	0,043
DK	77%	70%	0,302	0,340	0,639	0,042	0,036
ES	12%	39%	0,386	1,243	1,977	0,064	0,159
FI	38%	36%	0,452	0,510	1,805	0,024	0,137
FR	4%	27%	0,069	0,211	0,296	0,023	0,024
GR	11%	23%	0,961	1,120	4,346	0,136	0,606
HR	10%	34%	0,336	0,834	2,847	0,112	0,121
HU	22%	25%	0,552	0,701	0,767	0,243	0,046
IE	2%	30%	0,730	1,153	2,368	0,217	0,118
IT	31%	46%	0,464	1,093	1,542	0,160	0,100
LU	10%	26%	0,678	0,786	0,250	0,306	0,024
ME	0%	31%	0,918	1,096	5,247	0,029	0,416
NL	58%	45%	0,422	0,600	0,494	0,059	0,042
NO	1%	70%	0,006	0,018	0,008	0,003	0,013
PL	22%	29%	0,980	1,685	4,570	0,048	0,291
PT	14%	40%	0,509	1,403	2,999	0,157	0,101
RO	22%	39%	0,503	0,613	2,412	0,055	0,192
RS	0%	27%	1,001	1,768	11,834	0,031	1,912
SE	7%	91%	0,004	0,014	0,006	0,003	0,016
SI	3%	31%	0,669	1,589	11,007	0,040	0,293
SK	18%	30%	0,233	0,465	1,553	0,035	0,395
UK	8%	34%	0,576	1,026	1,306	0,074	0,096

* including Combined Heat and Power (CHP)
**Share of electricity generation in CHP produced thermal on total (conventional) thermal electricity production in 2005
Source: /Eurelectric 2007/

2.2 Transport modes

2.2.1 Passenger car

For the journey with passenger cars different vehicle types were defined:

Table 6 Characterisation of passenger cars

Emission Standard	Energy	Size	Load Factor
Conventional	Gasoline	Compact class (<1.4l)	Average (1.5 persons)
Euro-1, Euro-2,	Diesel	Medium sized class (1.4-2l)	Variation from 1-5 persons
Euro-3, Euro-4	LPG	Luxury class (>2l)	
Euro-5	Hybrid		

Energy consumption and emissions of passenger cars are different for each road category (highway, rural, urban). The urban emission factors include the extra emissions for cold start and evaporation. All values for EcoPassenger were estimated with the COPERT 4 model, version 6.1 /LAT 2009/. Country specific parameters could not be included, because they are not available. So assumptions are made for all parameter with influence on the energy and emission values of passenger cars. They are listed in the following table.

Table 7 Parameter settings for the estimation of energy consumption and emission factors with COPERT 4

Parameter		Values	
Average speed			
Urban / Rural / Highway (km/h)		30 / 75 / 100	
Mileage degradation:			
Mean fleet mileage Euro-1 / -2 / -3 / -4 (km)		100,000 / 70,000 / 40,000 / 20,000	
With IM effect			
Composition of conventional cars gasoline		**Total**	**100%**
Pre ECE			5%
ECE 15/00-01			10%
ECE 15/02			20%
ECE 15/03			25%
ECE 15/04			30%
Improved Conventional			5%
Open Loop			5%
Additional emissions for cold start and evaporation on urban roads:		**Supplement to warm emission factor:**	
Fuel Consumption		+15%	
NOx Gasoline		+100%	
NOx Diesel		+5%	
NMVOC Gasoline	conventional	+300%	
	Euro-1	+800%	
	Euro-2	+1,300%	
	Euro-3	+3,600%	
	Euro-4/5	+4,000%	
NMVOC Diesel		+50%	
PM		+40%	

2.2.2 Railways

The railway transport is differentiated according the system used in the UIC Energy Database /UIC 2009/ (see the following table).

Table 8 Characterisation of passenger trains

Transport Service	Traction Class
Highspeed	Electric
Intercity	Electric, Diesel
Regional/Urban	Electric, Diesel

The specific energy consumption values for EcoPassenger are derived from the UIC Energy Database for the year 2007 /UIC 2009/ and, for France, from country specific calculators Ecocomparateur /ADEME 2006/. These values will be updated every year from UIC energy/CO_2 database /UIC 2009/.

A specific value per passenger-km for different train service type has been used for seven countries: Belgium, Switzerland, Germany, Spain, Finland, France, United Kingdom and Sweden. For all other countries, a passenger kilometre weighted average value for each service type was used, based on the eight countries values. These values include the average country and service type specific load factors and are used as standard for the emission calculation in EcoPassenger. For the model feature “maximum ultilization” the specific energy values per seatkm (load factor=100%) are used. These values are available for six countries: Belgium, Switzerland, Germany, Spain, Finland, United Kingdom. The average numbers of the six countries are used as default values.

The following table summarizes the average values. The specific values per passenger-km for single train types in each country are property of UIC database.

Table 9 Average values for specific energy consumption of European trains

	Electric (Wh/Pkm)			Diesel (g/Pkm)	
	Highspeed	Intercity	Regional/Suburban	Intercity	Regional/Suburban
Average	70	77	1105	17	25
	Electric (Wh/seatkm)			Diesel (g/seatkm)	
	Highspeed	Intercity	Regional/sSuburban	Intercity	Regional/Suburban
Average	32	30	35	7.3	8.3
Sources: Data elaboration from UIC 2009 countries Database					

Emission factors for diesel engines

Emission factors for diesel engines are taken from the Rail Diesel Project /UIC 2006/ and the UmweltMobilCheck /IFEU 2008b/. An average emission factor for railcars and main locomotives has been estimated by RailDiesel with most representative engines of railway companies. For DB AG average values for Intercity and regional trains are available. For EcoPassenger we have used default values, which are derived from different sources, shown in the following table.

Table 10 Emission factors for diesel engines (in g/kg)

Transport service	CO_2	NO_x	SO_2	NMVOC	PM*
Average values Rail Diesel Project					
Railcars		40.0			1.0
Main Locomotives		64.7			1.15
DB AG 2007					
Intercity	2,941	55.7	0.02	2.5	0.6
Regional/suburban	2,941	42.8	0.02	2.1	0.6
Default Value / *Source*	*UIC indi-cators*	*Average Rail Diesel*	*S-content 10ppm*	*Average UMC*	*Average Rail Diesel*
Passenger Train	3,175	52.3	0.02	2.6	1.1

Remarks: *PM from combustion
Source: Rail Diesel project /UIC 2005/; UmweltMobilCheck /IFEU 2008b/

2.2.3 Air traffic

For air transport the methodology of the UmweltMobilCheck /IFEU 2008b/ is used. The methodology calculates energy and emissions of a flight dependent on flight distance and aircraft type. For the adjustment on recent European values additional information of the EEA Guidebook /EEA 2009/ and other information are used.

2.2.3.1 Flight phases

A flight is divided in different flight phases:

Taxi (rolling traffic)
Take-off and climb
Cruise
Dive and landing

The definitions for the flight phases are taken from /DLR 2000/. The length of each phase depends on the total distance, because for shorter distances the altitude of the cruise is lower. /DLR 2000/ defines flight phases fort the distance classes 250 km, 500 km, 750 km, 1000 km und over 1000 km.

For a special journey a flight profile must be selected which is appropriate. For short distance journeys the energy consumption and emissions strongly depends from the length of the journey. For a better differentiation of short distance journeys we defined additional profiles for 125 km, 375 km and 625 km. For the calculation eight profiles are available, which can be selected depending on the flight distance (see the following table).

Table 11 Flight profiles for different distance classes

Distance Class (km)	Distance (km) from –to	Length Climb (km)	Length Cruise* (km)	Length Dive (km)	Altitude (m)
125	0 – 187	27	35	62	3.000
250	188 – 312	69	53	128	4.615
375	313 – 437	101	111	163	6.050
500	438 – 562	132	170	197	7.484
625	563 – 687	163	247	215	9.050
750	688 – 875	207	276	267	9.430
1000	876-1.100	210	523	267	10.670
>1000	>1.100	212	>620	268	10.670
Remarks: *Distance classes 125, 375, 625 interpolated Source: DLR 2000, IFEU-assumptions					

2.2.3.2 Energy consumption and emission factors

The emission data base of the DLR in /DLR 2000/ includes energy and emission values fort the most important airplane types. Typical airplanes types for short and medium distance flights within Europe are the B737-family and A320-family. Information about the fleet structure are not available for this study. To estimate average emission factors we use – similar to /IFEU 2008b/ - the values of the three types A 320, B 737-

300 und B 737-500.

The specific energy consumption and emission factors are estimated as average values with the assumptions defined. The following table shows a selection of the values for the energy consumption.

Table 12 Energy consumption (in g/seatkm) for different engine types and average values used in EcoPassenger

Distance-class (km)	Flight phase	A320	B737-300	B737-500	Average
250	Take-off, climb	60	73	86	73
	Cruise	23	29	35	29
	Dive, landing	13	18	23	18
	Average	**29**	**35**	**43**	**35**
500	Take-off, climb	50	58	69	59
	Cruise	20	25	31	25
	Dive, landing	14	17	20	17
	Average	**25**	**30**	**37**	**31**
750	Take-off, climb	42	48	58	49
	Cruise	18	22	27	22
	Dive, landing	11	16	20	15
	Average	**22**	**27**	**33**	**27**
1000	Take-off, climb	42	50	60	51
	Cruise	16	20	25	21
	Dive, landing	9	13	16	13
	Average	**20**	**24**	**30**	**25**
No of seats		150	128	103	127
Source: DLR 2000, LH 2005 (No of seats), IFEU-assumptions					

For the rolling traffic on the airport (Taxi-Out, Taxi-In) for all engines additional consumption and emissions has to be considered. The values are taken from /LH 1993/. The additional consumption is about 1 kg kerosene per seat and und climb/landing cycle.

The carbon dioxide value of kerosene is 3.150 g/kg For PM_{10} (exhaust) the emission value of /EEA 2009/ is used (0.2 g/kg) /IFEU 2005/. The gasoline equivalent is 1.32 l gasoline/kg kerosene.

The following table summarizes all energy and emission values used for EcoPassenger.

Table 13 Specific energy consumption and emission factors for air traffic (this study)

Distance class	FC	CO_2	NOx	SO_2	NMVOC	PM
	g/Seatkm	kg/kg	g/kg	g/kg	g/kg	g/kg
125 km	40.9	3.150	12.8	0.06	0.52	0.04
250 km	35.4	3.150	11.5	0.06	0.34	0.04
375 km	33.2	3.150	11.5	0.06	0.25	0.04
500 km	30.9	3.150	11.6	0.06	0.15	0.04
625 km	28.3	3.150	11.4	0.06	0.18	0.04
750 km	27.2	3.150	11.2	0.06	0.21	0.04
1000 km	24.8	3.150	10.7	0.06	0.24	0.04
>1000 km	23.9	3.150	9.4	0.06	0.09	0.04
Taxi (g/Seat)	1,000.0	3.150	4.1	0.06	1.7	0.04
Source: DLR 2000, LH°1993, LH°2005, IFEU 2008b						

Comparison with EMEP/CORINAIR Emission Inventory Handbook

The EMEP/CORINAIR Emission Inventory Handbook /EEA 2009/ proposes to use the B737-400 as a representative engine for domestic flights, if no information about the fleet structure is available. The following table shows the comparable values, which have a good correlation with the values used in this study.

Table 14 EMEP/CORINAIR values for specific energy consumption and emission factors of air traffic

Distance class	FC	CO_2	NOx	SO_2	NMVOC	PM
	g/Seatkm	kg/kg	g/kg	g/kg	g/kg	g/kg
125 mi	39.6	3.150	13.1	1.0	0.14	0.2
250 mi	30.4	3.150	11.6	1.0	0.14	0.2
500 mi	26.0	3.150	10.9	1.0	0.11	0.2
Taxi (g/Seat)	2,700.0	3.150	4.3	1.0	1.8	
Remark: based on B 737-400 with 135 seats Source: EEA 2009, IFEU calculations						

See also Appendix 5 for a comparison with the existing calculators for airlines.

2.2.3.3 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 2007/). 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 9 kilometres. These are usually reached in the cruise phase of flight distances of greater than approx. 400–500 km /ATMOSFAIR 2007/. Therefore in EcoPassenger the RFI factor is included as an **option** for flights with distances over 500 km. The following assumption are made:

- Distance class 500 km: 50% of all flights reach critical altitudes
- Distance class 625 km: 75% of all flights reach critical altitude
- Distance class 750 km and more: all flights with critical altitudes (100% RFI)
- Only the distance travelled during cruise is critical.

For cruise in critical altitudes a RFI factor of 3 is used (this means that the direct CO_2 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 following average RFI factors dependent from flight distance are used in EcoPassenger:

Table 15 Average RFI factors for different distance classes

Distance class (km)	Average RFI factor
500 km	1.27
625 km	1.47
750 km	1.6
1000 km	1.87
>1000 km	2.5
Remark:: Average RFI factor for different flight cycles without taxi Source: ATMOSFAIR 2007, IPCC 1999, IFEU assumptions	

2.2.3.4 Load factors

The load factor for passenger flights within the EU ranges from 63% to 80% for the top ten airports (2005) /EUROSTAT 2007b/. From this we estimate an average load factor of 72% for the average flight in EcoPassenger. Similar values can be found in the German statistic /StatBA 2007/. The web tool gives also the possibility to the customer to choose the maximum utilization

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4 Appendix: Description of important data sources

COPERT 4

Copert 4 is an MS Windows* software program which is developed as a European tool for the calculation of emissions from the road transport sector. The emissions calculated include regulated (CO, NOx, VOC, PM) and unregulated pollutants (N2O, NH3, SO2, NMVOC speciation) and fuel consumption is also computed.

Copert 4 was funded by the EEA and is used in different European countries and in the EU. The recent data set of emission factors was developed by a European research project called ARTEMIS which is based on a broad set of emission measurements and methodologies developed by leading European scientists in the field of transport emissions. In EcoPassenger the Version 6.1 from 2009 is used.

Railenergy

Railenergy is an Integrated Project co-funded by the European Commission under the 6th Framework Programme for Research and Development. The full name of the project is "Innovative Integrated Energy Efficiency Solutions for Railway Rolling Stock, Rail Infrastructure and Train Operation."

The overall objective of Railenergy is to cut the energy consumption by developing a holistic framework approach, new concepts and integrated technical and technological solutions to improve energy efficiency. The holistic approach is at the heart of the project, creating the spirit for the proper integration and synergies of the combined results.

Railenergy will address the problem of energy efficiency within an optimised railway system thus contributing to a reduction in the life cycle costs of railway operation and of CO2 emissions per seat/kilometre or tonne/kilometre. The project target is to achieve a 6% reduction in the specific energy consumption of the rail system by 2020, assuming that traffic volumes double in comparison with current figures.

Rail Diesel Project

As cornerstone of the “UIC Diesel Action Plan” a one-year “Rail Diesel Study”, co-funded by the European Commission, was performed in 2005.

Partners of the UIC for this study have been the Community of European Railways (CER), the Union of European Railway Industries (UNIFE), the European Association of Internal Combustion Engine Manufacturers (Euromot) and AEA Technology as external consultant.

EMEP EEA Emission Inventory Guidebook – 2009

The Guidebook has been prepared by the Convention’s Task Force on Emission Inventories and Projections (TFEIP), with detailed work by the Task Force’s expert panels and the European Environment Agency (EEA). The present edition of the Guidebook replaces all earlier versions. The Guidebook is compatible with, and complementary to, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Its intention is to support reporting under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU directive on national emission ceilings.

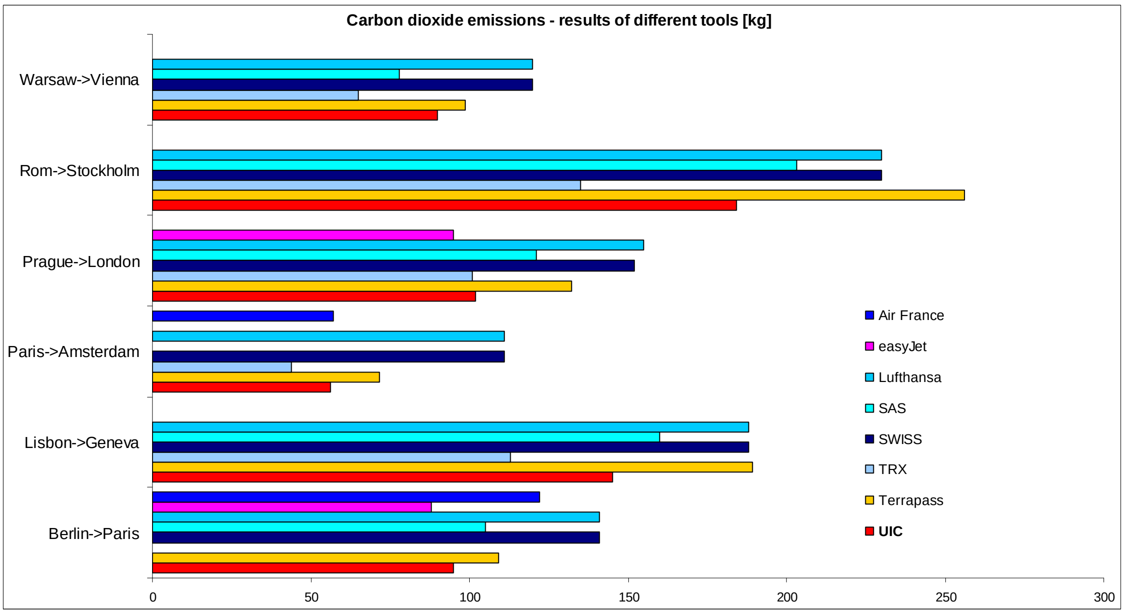
The ecoinvent Centre

The ecoinvent Centre offers science-based, industrial, international life cycle assessment (LCA) and life cycle management (LCM) data and services. The ecoinvent Centre is the world's leading supplier of consistent and transparent life cycle inventory (LCI) data of known quality. It was established in the late nineties in a joint initiative of the ETH domain and Swiss Federal Offices.

The newest ecoinvent data v2.1 contains international industrial life cycle inventory data on energy (including oil, natural gas, hard coal, lignite, nuclear energy, hydro power, photovoltaics, solar heat, wind power, electricity mixes, bioenergy), transport, building materials, wood (European and tropical wood), renewable fibres, metals (including precious metals), chemicals (including detergents and petrochemical solvents), electronics, mechanical engineering (metals treatment and compressed air), paper and pulp, plastics, waste treatment and agricultural products. The ecoinvent data v2.1 is used by more than 1200 members in more than 40 countries worldwide and is included in the leading LCA software tools as well as in eco-design tools for building and construction, waste management and product design.

5 Appendix: Comparison of different aircraft CO_2-calculators

For aircraft transport several CO2-calculators by different organisations are available in the internet. For the checking of the results of EcoPassenger the CO2-emissions for different relations were compared with the results of different calculators (without RFI). In general, the results of EcoPassenger ranges in an average field of all results. The following diagram shows the results of the comparison.



6 Appendix: International Country Codes

AT	Austria
BE	Belgium
BG	Bulgaria
CH	Switzerland
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LU	Luxembourg
ME	Montenegro
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

7 Appendix: Conversion Factors

	Density	**Energy Content**
Gasoline	0.742 kg/l	43.543 MJ/kg
Diesel	0.832 kg/l	42.96 MJ/kg
Source: Mineralölwirtschaftsverband (MWV) www.mwv.de, Arbeitsgemeinschaft Energiebilanzen: www.ag-energiebilanzen.de		