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Carbon Footprint and environmental impact of Railway Infrastructure

commissioned by International Union of Railways (UIC

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List of abbreviations

Abbr.	Explanation
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
EU	European Union
EPD	Environmental Product Declarations
g	gram
GHG	greenhouse gas
GWP	Global Warming Potential
HDPE	High Density Polyethylen
HSR	high-speed rail
ICE	Inter City Express
IPCC	International Panel on Climate Change
ISO	International Organization for Standardization
Kg	kilogram
km/h	kilometre per hour
kWh	kilowatt-hour
N_2O	nitrous oxide (laughing gas or sweet air)
NMVOC	non-methane volatile organic compounds
NO_x	nitrogen oxide
pkm	passenger-kilometres
PCR	Product Category Rules
PM10	particulate matter
PVC	Polyvinylchlorid
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide
TGV	Train á Grande Vitesse
tkm	tonne-kilometres
UIC	Union Internationale des Chemins de fer

1 Introduction

Comprehensive tools for the comparison of the environmental impact of different transport modes have been developed. The International Union of Railways UIC has worked out two tools: "EcoTransIT" for freight- and "EcoPassenger" for passenger transport. Both on-line calculators focus on the operation of vehicles and take the upstream emissions from energy supply into account. Infrastructure such as track system or the production of vehicles (see Figure 1.1) is excluded. Especially within large rail projects, policy makers and the public wondered if the share of track and vehicles construction is significant. Relevant issues are:

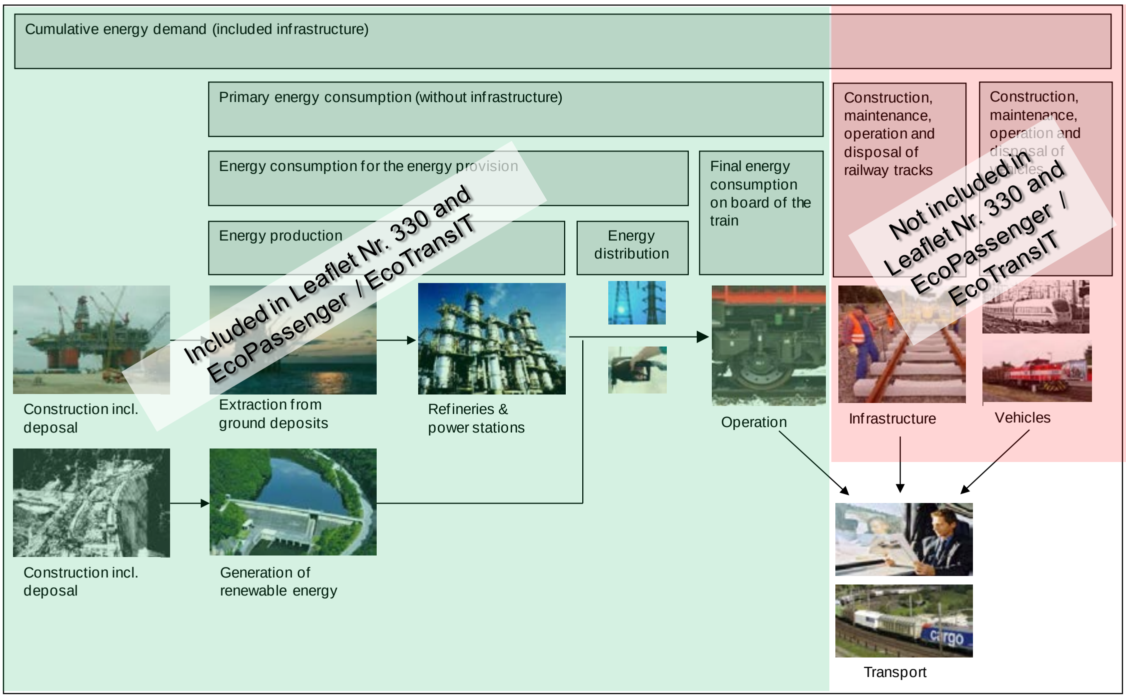
- What is the carbon footprint of the construction of viaducts and tunnels?
- What is the environmental impact of transport network density, rail utilization numbers, and composition of the electricity mix in proportion to the carbon footprint of the infrastructure?
- Does the inclusion of infrastructure (tracks, vehicles) significantly change the relation of greenhouse gas emissions between road and rail?

1.1 Goals & Scope

The purpose of the study is:

- to develop a methodology and a calculation tool in order to determine the carbon footprint and the environmental impact for railway infrastructure, based on a comprehensible and easily applicable methodology,
- to identify and collect data needed to determine the carbon footprint of railway infrastructure of different European countries,
- to determine the carbon footprint of infrastructure for selected countries compared to the total impact of railway transport (operation and infrastructure).

Figure 1.1 Scheme of relevant processes for rail transport



The elements on the left side (green color) are covered by the existing tools of eco-TransIT / EcoPassenger, the elements on right side (construction, maintenance and disposal of railway tracks and rolling stock) are within the focus of this study. Source: UIC (2010)

1.2 Structure of report

An overview of the existing studies concerning the infrastructure of transport can be found in the next chapter of this study. In chapter 3 the methodology and data sources for accounting the rail infrastructure are given.

In the 4th chapter, the different elements of rail infrastructure (track, buildings and vehicles) are described and the result of the environmental assessment of each element is shown. In the 5th chapter, the impact of rail infrastructure for selected countries is calculated (Germany, Switzerland, France, Italy, Spain, Norway, Belgium, Japan and India). The calculation of other railway networks is possible through the embedded calculator on page 30 in this chapter.

The annex in chapter 7 comprises additional information as the Excel file for the environmental assessment and the factsheet of the literature review.

2 Literature review

Several studies concerning infrastructure of transport modes have been published recently. The following literature has been analysed for this study:

- **High Speed Rail (Germany)**
  by Rozycki, Koeser & Schwarz (2003); Uni Halle (2002)
- **Ecoinvent: Sources & Compilations (Switzerland)**
  Spielmann, Dones & Bauer (2007); Tuchschmid & Halder (2010);
  Frischknecht & Stucki (2009)
- **Environmental Inventory of Passenger Transportation (USA)**
  Chester (2008); Chester & Howarth (2009), Chester & Howarth (2010)
- **Product Category Rules for Railways (Sweden)**
  EPD (2009)**;** EPD (2010)
- **Whole Carbon Footprint of Railways (Great Britain & Germany)**
  RSSB (2010); Schmied & Mottschall (2010)
- **Carbon Footprint of High Speed Transport (France & California)**
  Tuchschmid (2010); SNCF & Ademe (2009); UIC (2011); Chang & Kendall (2011)
- **various**
  Kendall, Harvey & Lee (2009); Keoleian et al. (2005); EPD (2011); Stripple (2001)
  Loffredo & Fedele & Severini (2011); Zimmer et al. (2009)

Each study was analysed and is described in a structured table with similar format in Annex 7.3. This allows a good overview and a quick cross check for the content of each study. However, it was not possible to read and evaluate all studies in detail or to analyse and compare the different approaches and data sources. The following conclusions can be drawn from the review:

- During the last decade a lot of efforts have been made to examine the environmental impact of transport infrastructure with a clear focus on new highspeed railway lines.
- The developped methodologies are applicable and comparable, although the system boundaries often differ. This is the reason, why a direct comparison of the values between the studies is not possible.
- The Ecoinvent database is a very common source of impact factors in European studies with regard to all transport modes.
- Surveys from Chester et. al. for passenger transport in the USA found higher shares of CO_2-emissions for transport infrastructure than European studies. The reasons for the difference are not clear and need deeper analysis.
- A systematic research of the environmental impacts of infrastructure of road, ship and aircraft for European countries is still missing

In Table 2.1 you find an overview of different studies and their subject. Please note that not all surveys listed here were used in this study.

Table 2.1: Overview of selected studies dealing with carbon footprint of railway infrastructure and other modes

No.		[1],[2]	[3]	[4]	[5]	[6].[7],[8]	[8]	[12],[15]	[13]	
Short Title	**EcoTransIT, EcoPassenger**	**von Rozycki & Koese & Schwarz 2003**	**Spielmann & Dones & Bauer 2007**	**Frischknecht & Stucki 2009**	**Tuchschmid 2010 (Mobitool)**	**Chester 2008 Chester&Howard 2009 Chester&Howard 2010**	**EPD 2009**	**Tuchscmid 2009 Systra 2011**	**Schmied & Mottschall 2010**	**This Study**
1. Upstream processes										
- production of traction energy	included	included	included	included	included	included	included	included	included	included
- production of stationary energy		included							included	included
2. Vehicle fleet										
- locomotives	O	O,M,C	O,M,C,D	O,M,C,D	O,M,C,D	O,M,C	O,M,C,D	O,C	O,M,C	O,M,C
- wagons	O	O,M,C	O,M,C,D	O,M,C,D	O,M,C,D	O,M,C	O,M,C,D	O,C	O,M,C	O,M,C
- railcars	O	O,M,C	O,M,C,D	O,M,C,D	O,M,C,D	O,M,C	O,M,C,D	O,C	O,M,C	O,M,C
3. track system										
- normal track		O,M,C	O,M,C,D	O,M,C,D	O,M,C,D	O,C,M	O,M,C,D	O,C	O,M,C	O,M,C
- bridges		O,M,C	O,M,C	O,M,C	O,M,C,D		O,M,C,D	O,C	O,M,C	O,M,C
- tunnels		O,M,C	O,M,C	O,M,C	O,M,C,D		O,M,C,D	O,C	O,M,C	O,M,C
- embankments		O,M,C			O,M,C,D		O,M,C,D	O,C	O,M,C	O,M,C
- catenary equpment		O,M,C	O,M,C,D	O,M,C,D	O,M,C,D	O,C,M	O,M,C,D	O,C	O,M,C	O,M,C
- substations		O,M,C			O,M,C,D	O,C,M	O,M,C,D	O,C	O,M,C	O,M,C
- signals and communication		O,M,C			O,M,C,D		O,M,C,D		O,M,C	O,M,C
4. Other buildings										
- railway stations		O,M,C				O,C,M	O,M,C,D	O,C	O,M,C	O,M,C
- maintenance centers		O,M,C				O,C,M	O,M,C,D	O,C	O,M,C	O,M,C
- Terminals		O,M,C					O,M,C,D		O,M,C	O,M,C
- administration buildings							O,M,C,D			
- parkings						C,M	O,M,C,D			
- noise protection							O,M,C,D			
5. other modes									**Legend**	
- Road	included		included	included	included	included			**O**	Operation
- Ship	included		included	included	included	included			**M**	Maintenance
- Aircraft	included		included	included	included	included			**C**	Construction
									D	Disposal

3 Methodology for assessment of rail infrastructure

Based on the Pre-Study (UIC, 2010) and the report by Schmied & Mottschall (2010) a framework for assessing the traffic infrastructure has been developed. While developing the methodology, the following considerations have been taken into account:

- The methodology can be applied with normal office tools among the railways. This means that no new software or databases are needed
- The core ideas and calculations are widely accepted within the scientific community, government and the public opinion.

Within the first section, a short description of the indicators is given. The second section describes the modeling principles and the allocation of the impact. In the last section, the used data sources have been described.

3.1 Indicators

The method chosen in this study allows the impact assessment of any emissions or resources. For the sake of practicality, it is appropriate to make a selection. The following six key indicators cover a broad range of environmental criteria.

- Primary energy
- CO_2 (global warming potential)
- Particulate matter (PM_{10})
- Non-methane hydrocarbons (NMHC)
- Nitrogen oxide (NO_x)

These six indicators are also in use for the two UIC-Tools EcoPassenger and EcoTransIT. The calculation with other impact categories can be done with almost none additional effort.

3.1.1 Primary energy

Description: The primary energy includes the direct energy consumed for the train operation, the energy used in the upstream energy production processes as well as losses from electric power generation and distribution. All processes involved in extracting the energy from the environment are traced back to the point of origin, i.e. the place where the energy is extracted. For petrol or diesel, for example, this would be when the oil is taken out of the ground. Rotational or mechanical energy is considered to be the primary source of energy for renewable energy systems such as hydropower and wind power (Hischier et al., 2009).

Relevance to society: It is considered highly likely that global oil production will peak within the coming decades; after this point oil production will go into decline. This was predicted over 50 years ago by Hubbert (1949). Moreover, subsequent generations will be deprived of the opportunity of using petroleum as the chemical basis for a variety of products.

Unit: MJ-equivalents

3.1.2 CO_2 as an indicator of greenhouse gas potential

Description: The anthropogenic greenhouse effect is caused mainly by the emission of carbon dioxide (CO_2) from the burning of fossil fuels, although other greenhouse gases, principally methane (CH_4) and nitrous oxide (NO_2, also contribute significantly to global warming. Irrespective of the engine technology employed, CO_2 is the largest component of the transport sector's contribution to the greenhouse effect.

Relevance to society: It is considered proven that the heightened greenhouse effect is changing the climate and heating up the atmosphere. This has far-reaching consequences for mankind and for the biosphere and endangers the well-being of future generations (IPCC, 2007).

Unit: kilogram

3.1.3 Particulate matter: PM_{10} und $PM_{2.5}$

Description: Particulate matter (PM_{10} and $PM_{2,5}$) is the term for all airborne solid or liquid particles measuring between 10 micrometres (PM_{10}) and 2.5 micrometres ($PM_{2,5}$) in diameter that do not immediately settle to the ground. In addition to natural sources (pollen, forest fires, Saharan dust), a variety of human induced sources (traffic, wood heaters, electricity and thermal power stations) are responsible for increasing the concentration of particulates in the atmosphere (PSI, 2008). Particulate emissions from combustion processes are typically smaller than 2.5 micrometres. Transport is also responsible for the emission of particles as a result of abrasion processes, although these particles are normally larger than 10 micrometres. In urban areas, traffic is estimated to be responsible for around 20 percent of the emissions of particulates, although it is around 30% on average (BGBI, 2006).

Relevance to society: Particulate matter is a problem mainly because of its adverse health effects. These include temporary irritation of breathing passages (e.g. coughing), an increased need for medication by asthma sufferers and increased mortality from illnesses of the respiratory and circulatory systems. The toxicity of the particles depends both on their composition and their size. The increased health risk from diesel exhaust particulates comes from their carcinogenic components and the very small size of the particles (Frischknecht, Steiner, & Jungbluth, 2008; Knörr, 2008a). Fine particles can migrate to the alveolar region of the lungs. For reasons of data availability and practicality, no weighting has been applied to the location of the emissions[1].

Unit: Gram. The properties of the particles are not taken into account, as the life-cycle inventories contained in the ecoinvent database do not distinguish between different types of fine particulates.

3.1.4 Non-methane volatile organic compounds: NMVOC

Description: Volatile organic compounds are organic materials that vaporise easily (i.e. they are volatile) and exist in gaseous form at low (e.g. ambient) temperatures. For purposes of analysis, the gas methane is often excluded from the group of VOCs, which

[1] Particulates are a particular problem in urban areas.

results in a group known as NMVOC (non-methane volatile organic compounds).[2] NMVOCs are emitted into the atmosphere by a wide range of anthropogenic bioprocesses.

Relevance to society: Alongside nitrogen oxides, NMVOCs are a precursor of "summer smog" (ground-level ozone), making them relevant even when their source is predominantly outside cities. Some of the substances in this group (such as benzene) are also carcinogenic.

Unit: Gram

3.1.5 Nitrogen oxides: NO_x

Description: Nitrogen oxides are gaseous oxides of nitrogen. They are often abbreviated to NO_x because of the many oxidation states of nitrogen and the number of nitrogen-oxygen compounds. Nitrogen oxides are formed when nitrogen is exposed to oxygen under external energy input, typically from combustion processes.

Relevance to society: Nitrogen oxides have a range of adverse effects that are socially relevant. For example, nitrogen oxide reacts with moisture in the air to form nitric acid, which contributes to the formation of acid rain. The same mechanism can act upon the human mucous membranes and cause irritation of the respiratory organs (or, following chronic exposure, even damage). Moreover, nitrogen oxides are an important contributor to the formation of smog, ground-level ozone (in combination with NMVOC and UV radiation) and secondary particles (particulates).

Unit: Gram

[2] There is, however, no standard definition of what NMVOCs actually contain. Some definitions include information on steam pressure, while others define NMVOCs and VOCs in terms of their photochemical reactivity as a precursor in the formation of ground-level ozone. In Switzerland, emissions of VOCs are subject to the fiscal ordinance of November 12, 1997 (VOCV, 2009). In this project only the elementary flow 'NMVOC, unspecified "of ecoinvent dataset has been analyzed. This means that the emission tends to be underestimated (eg. for passenger transport by car: + 25.7%, respectively long-distance train. +20.9%).

3.2 Modeling principles

The assessment of the railway infrastructure is mainly based on the Pre-Study (UIC, 2010), Schmied & Mottschall (2010) and the Ecoinvent-methodology (Spielmann u. a., 2007). Please note, that this methodology can be applied for every network or transport service, see also section 3.2.8

3.2.1 Modeling Approach

This study follows the approach of Schmied & Mottschall (2010) for Germany "Treibhausgasemissionen durch die Schieneninfrastruktur und Schienenfahrzeuge in Deutschland" (Greenhouse gas emissions of railway infrastructure and vehicles in Germany). In principle, the estimation of the environmental impacts is carried out using an orienting material flow analysis[3].

3.2.2 System Boundaries

The choice of the system boundaries is essential: If the boundaries have been too narrowly defined, the result is not a complete assessment. In contrast, the assessment may focus on any processes but not the core product / core service if too many processes are in the system boundaries. In addition, the effort for data collection will rise rapidly as well as the calculation of the processes. Basically, one needs to ask oneself the question whether an outside activity is directly associated with the core process or not.[4] The following processes of rail infrastructure were considered, they are briefly described in chapter 4:

- **Upstream processes:** production of traction and stationary energy (see Figure 1.1),
- **Vehicle fleet:** construction, operation and maintenance of locomotives, wagons and railcars,
- **Track system:** construction, operation and maintenance of rail track, bridges, tunnels, embankments, catenary equipment, substations, telecommunication & signalization, energy equipment, buildings,
- **Other Buildings:** construction, operation and maintenance of railway stations, maintenance centers and terminals (optional).[5]

Some processes have not been taken into account:

- Abrasion of wheels, brakes and the overhead contact line

[3] A detailed life cycle assessment is beyond the scope of this study. The methods used in this study (material flow analysis) are in line with the product category rules for rail infrastructure and rail vehicles (EPD, 2009). These PCR-Rules are in close connection with the ISO standard 14025 (environmental declarations) and the ISO standard 14040 (Life Cycle Assessment).

[4] An example: The refining of crude oil for diesel production is directly linked (material flow) for operating the rolling stock. In contrary, the daily displacement of the railway workers to their offices for securing a proper operation of the trains is not linked with the transport performance itself.

[5] A railway station also fulfils the functions of shopping malls, restaurants and service centres today. These services are not linked with the core service of transporting passenger. Within this study, the operation of buildings can be taken into account as an option

- first mile / last-mile of the passenger
  Before a passenger may board a train, he has to get to the station with some other means of transportion(first mile). Similarly, the destination station is rarely the desired destination (last-mile).[6]
- infrastructure of stations / parking
  Buildings and structures for the smooth connection to public transport as buses and parking lots to private transports are necessary. Within this study, it is assumed that these facilities are part of the respective network of public buses, respectively private cars.

3.2.3 Lifespan of considered elements

All elements of rail infrastructure have to be replaced after some time due to technical problems or material fatigue. Therefore, the question of the appropriate lifespan rises. In this study an average lifespan of 60 years has been considered for the construction of civil engineering (e.g. tunnels, buildings). This is in line with PCR for railways (EPD, 2009). However, a sensitivity analysis was done for a lifespan of 100 years, as many tunnels and bridges are still operated today even 100 years after construction (see page 34 in chapter 5.2.2).

[6] If national data in comparable quality is available for the first mile / last mile, a complete carbon footprint can be calculated. However, within this study the first mile / last mile could not be considered due to the limited data access and missing values for the infrastructure of cars, buses and trams

Table 3.1: Considered lifespan of the assessed elements

	lifespan
	years
rail for tracks	30
earth work for track	60
sleeper (concrete)	35
sleeper (wooden)	30
sleeper (iron)	30
sleeper, closed lane	30
bridge, viaduct	60
bridge, concrete	60
bridge, iron	60
tunnel, open pit	60
tunnel, mining	60
Building: Junction for intercity trains	60
Building: Junction for local trains	60
Building: Stop for local trains	60
Building: Railway station (stop for freight trains)	60
Building: Site for maintenance / repairing	60
Building: Transformer Substation: Building	60
Building: Transformer Substation: Electrical Installations	15
Source: Schmied & Mottschall (2010)	

3.2.4 Modelling the impact of rail infrastructure

The modules for rail infrastructure comprise the civil engineering work as tunnels and bridges, energy provision, communication and the track itself. Due to the fact that various elements of infrastructure are characterized by a different life span all carbon footprints are calculated for one year. To assess the environmental impacts of the rail infrastructure, the following approach has been used:

- Step 1: A specific module (one unit or one kilometre) has been assessed in order to estimate the material flow, the needed transportation and the emission of the construction itself (e.g. the energy needed for tunnel drilling machines). Additionally, the material for maintenance has been calculated on a yearly base and added (e.g. one concrete sleeper has to be replaced every year on a 2 km long single track[7]).
- Step 2: These sums of materials and emissions have been multiplied with the respective impact factors of the Ecoinvent-database (see section 3.3). This results in the overall impact of the specific module.
- Step 3: The overall impact is being divided by the average lifespan of each element in order to get the impact per kilometre and year, resp. per unit and year.

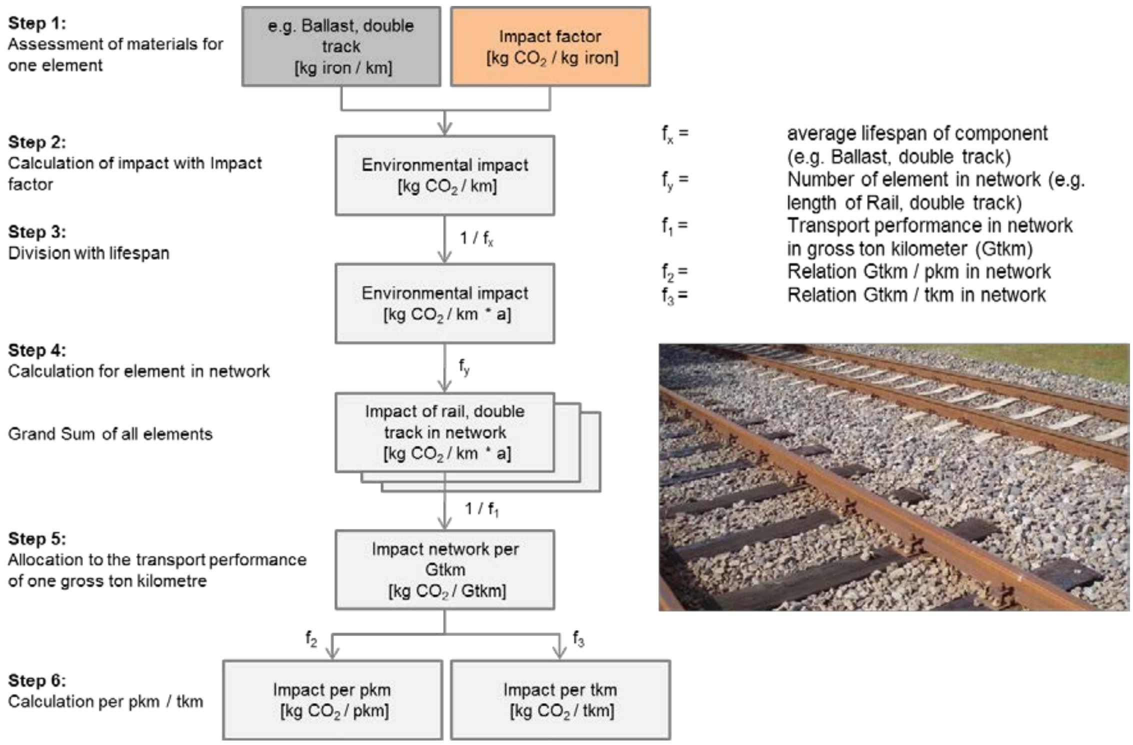
[7] Please note the difference between the yearly replacement through maintenance and the considered lifespan of the element itself: The lifespan of the concrete sleeper has been modelled as 35 years, additionally one sleeper per 2km of single track will be replaced through normal maintenance.

Functional unit for rail infrastructure modules:
[impact per km and year] resp. [impact per unit and year]

- Step 4: This step includes the multiplication of the specific module emissions with the number of modules of the considered network. In this way, the overall emissions of a specific network (e.g. in a country / a high-speed track / the network for regional trains / a specific line) can be calculated according to the respective conditions and topography.
- Step 5: As different kinds of trains (e.g. freight vs. passenger trains) are operated in the network, one has to allocate the impact to each transport service. This allocation of the network impact is done by gross tonne kilometre. Therefore, one has to divide the total emission of the network per year by the total transport performance of the network in gross tonne km to get the specific impact.
- Step 6: The last step is the calculation to the unit of passenger kilometre, respectively net tonne kilometre: The impact per gross tonne kilometre is being multiplied with the ratio of gross tonne kilometre / passenger kilometre, resp. gross tonne kilometre / net tonne kilometre

Functional unit for using the rail network:
[impact per pkm] resp. [impact per tkm]

Figure 3.1 Impact calculation of the rail infrastructure[8]



Example of calculation: Impact of track ballast

A track consists of steel rails on sleepers, which are laid on a bed of ballast. The track ballast is customarily crushed stone, in order to support the ties and allow some adjustment of their position. For a double track of 1000m, around 2600 m^3 of crushed stone are needed (Step 1).

The production and transport of this ballast is linked with a carbon footprint of almost 24 tonnes CO_2 (Step 2). As the ballast is replaced every 25 years, the annual carbon footprint per kilometre track can be calculated by a division of 25: 959 kg of CO_2 are emitted from the ballast of 1km double track. (Step 3)

[8] Image: LooiNL (2007)

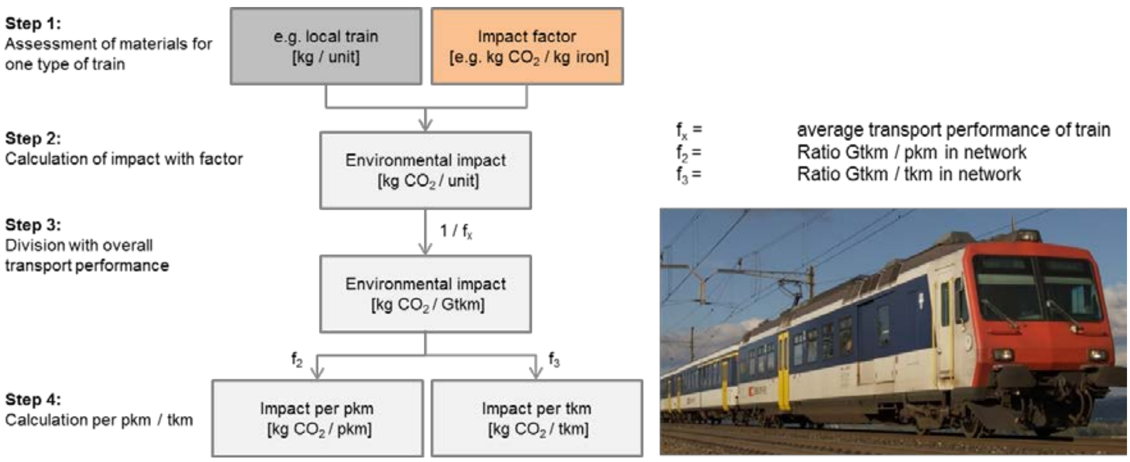
3.2.5 Modelling the impact of rolling stock

The estimation of the impact through the rolling stock (vehicle production and maintenance) includes the following steps:

- Step 1 & Step 2: Assessment of the environmental impact of vehicle production, maintenance and disposal (determination of the amount of each material, multiplied with the respective emission factors of the Ecoinvent-database).
- Step 3: Division of the impact through the transport performance in Gtkm (total gross tonne kilometre of the train over the lifetime)
- Step 4: Determination of the Ratio Gtkm / pkm, respectively Ratio Gtkm / tkm and multiplication in order to get the impact of rolling stock.

▪ **Functional unit for using the rolling stock:** [impact per pkm] resp. [impact per tkm]

Figure 3.2 Impact calculation of the rolling stock[9]



[9] Image: Gubler (2007)

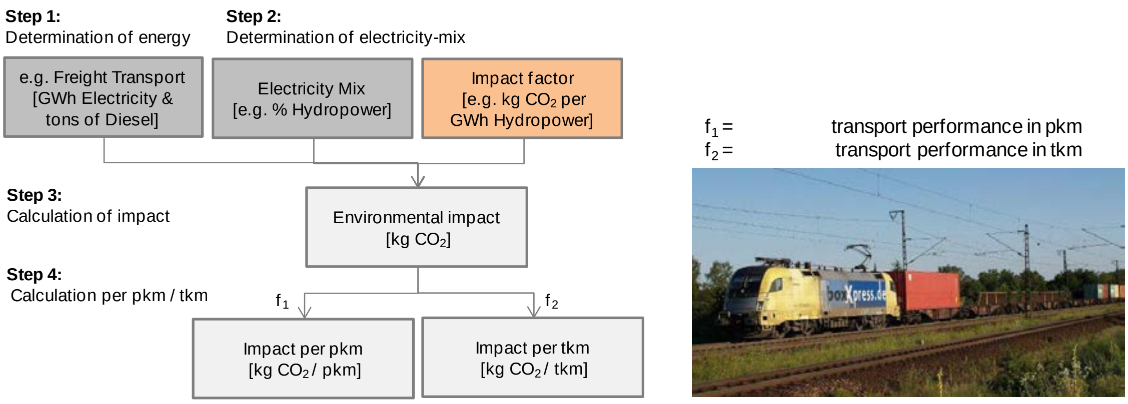
3.2.6 Modelling the impact of train operation

The operation phase is modelled as top-down approach: The overall energy consumption of the trains is calculated from the respective emission factors. The following steps are necessary:

- Step 1: Determination of the energy consumption, here the source is either the Energy and CO_2-database of UIC mainly for European countries or the annual statistics of UIC (2009), see also section 3.3
- Step 2: Determination of the electricity mix, according to the UIC Energy and CO_2 database or the national electricity mixes (data of the international Energy Agency IEA).
- Step 3: Multiplication of the energy consumption with the respective emission factors.
- Step 4: Division of the impact with the transport performance in passenger kilometre or net tonne kilometre.

> - **Functional unit for train operation**
>   impact per pkm] resp. [impact per tkm]

Figure 3.3: Impact calculation of the operation[10]



[10] Image: Knörr (2011)

3.2.7 Modelling transport services

The impact of the transport service of a passenger kilometre or a net tonne kilometre is the grand sum of the rail infrastructure, the rolling stock and the operation. As an option, the impact of the building operation[11] can be added.

3.2.8 Transport on different networks, e.g. local trains

The transport by rail consists of passenger and freight transport, within passenger transport, one may further distinguish local trains, intercity trains and high speed trains. These different transport services uses different parts of the network, e.g. on the high speed track between Strasbourg and Paris hardly any local train is operated. The described methodology is valid for all kinds of networks and transport services:

- The rail transport of a single line between two stations can be assessed, e.g. the impact of a new built high speed line.
- A detailed bottom-up analysis of the network can be done with the impact estimation of single lines then aggregated to a distinct network[12].With this bottom-up approach, one would get locally dispersed data in a high quality.
- A country-specific network may be assessed in a top-down approach. Due to the limited data availability, this study consists of the analysis of 7 country-specific networks as top-down approach. Section 5.2.1 highlights the differences between a bottom-up and a top-down approach.

3.2.9 Considerations

Assumption on temporal scope

A crucial assumption is to model past processes of material inputs as they would happen today. Two implications result from this assumption:

- Past emissions have the same emission values and are equally accounted as actual emissions. This is contrary to the normal calculations of the UNFCC body in the framework of the Kyoto-protocol, where only actual emissions are taken into account.
- Technological changes of production processes are not considered: For instance, concrete, which has been used in the construction of tunnels in 1980, is represented by a state of the art production in 2000.

[11] The impact calculation of the buildings operation consist the following steps: 1) Determination of the consumed energy 2) Multiplication with the emission factors 3) Division by the overall transport performance in gross tonne kilometre 4) Determination of the ratio Gtkm / pkm, resp. Gtkm / tkm and multiplication.

[12] This would require the determination of the specific network details and its transport performance on each section. Then the impact can be calculated for each section of the rail network. The study bySchmied & Mottschall (2010) followed this approach, see also section 5.2.1

No consideration of deforestation

The impact of the deforestation generated by the track construction was not taken into account. According to environmental specialists, only a growing vegetation absorbs CO_2 and in most cases it is very difficult to estimate feasible emissions if the vegetation is not burned.

Cut-off criteria

According to the Product Category Rules, products and activities of no more than 1% of the total environment can be neglected. If the direct environmental effects are not known, the 1% rule may base on the amount of material. In rail vehicles, a variety of materials are used, but of which a majority covers only very small amounts. These materials are therefore not taken into account.

3.3 Data sources & Impact factors

Three main data sources were used within this study:

- For emission factors (e.g. materials, energy or electricity) the ecoinvent-database v2.2 has been chosen. The reasons are the high reliability, the transparent documentation and the international usage of data also within the rail sector[13] (see table Table 3.2 with some of the used emission factors).
- The report by Schmied & Mottschall (2010) about the Greenhouse gas emissions from infrastructure of the German rail network and the rolling stock is the most topical and comprehensive study. Therefore almost all of the described railway elements stem from this source.
- Further sources are the two carbon footprint studies of the high speed traffic on behalf of the UIC (2010, 2011).
- The data for deriving the country sheets stems from the UIC-Statistics (2009), the UIC Energy and CO_2 database and a questionnaire developed and sent out in this survey.

Table 3.2: Selected emission factors from Ecoinvent v2.2

Usage	Name of ecoinvent-DS		**CO_2**	**CED[14]**	**PM_{10}**	**SO_2**	**NO_x**	**NMVOC**
			kg	MJ-equ.	g	g	g	g
Excavation for earthworks	excavation, hydraulic digger	m3	0.5	8.1	0.6	0.8	6.1	0.9
Ballast	gravel, crushed, at mine	t	4.1	138	4.7	9.5	22.1	4.2
Concrete sleeper, Buildings, stations,	concrete, exacting, at plant	m3	317	1782	57	203	558	82
Radio pole, rail	steel, converter, un-alloyed, at plant	kg	1.5	23.3	4.5	3.2	3.3	0.5
Aerial contact line, electric substation, cables,	copper, at regional storage	kg	1.7	34.0	19.5	103.3	21.3	3.7
Transport of all kinds of material	transport, lorry >32t, EURO5	tkm	0.1	1.8	0.04	0.12	0.39	0.13
Transport of backfill / excavation material	transport, freight, rail, diesel	tkm	0.0	0.8	0.03	0.10	0.19	0.03
Source: Ecoinvent v2.2								

[13] Both UIC-Tools „EcoPassenger“and „EcoTransit“ use the ecoinvent-database for modelling the upstream processes.

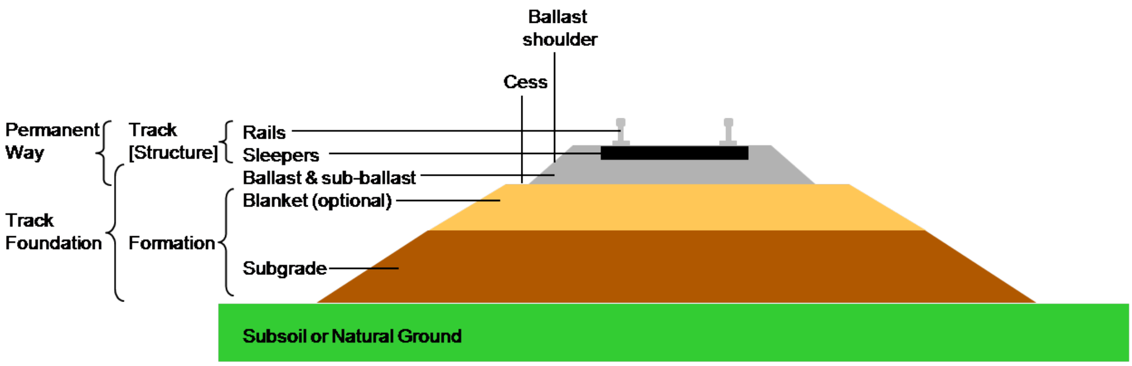
[14] CED stands for Cumulative Energy Demand and is the same as primary energy.

4 Assessing the rail infrastructure

4.1 Construction and maintenance of tracks

The construction of the tracks consists of earthworks for levelling the underground, construction of civil engineering as bridges and tunnels, construction of the track bed itself with the ballast and the rail and the installations for electricity provision (catenaries and overhead wiring) and communication / signalization. The maintenance of the elements is also considered, mainly in slightly higher amounts of material (e.g. 1% per year for maintenance)

Figure 4.1: Scheme of rail track



4.1.1 Earthwork

The general construction of a railway track is shown in Figure Figure 4.2. The base of a rail track consists of a foundation layer of gravel and sand over the existing ground floor. If the route goes through hilly areas, some embankments or cuttings are also necessary. Tunnels and bridges need additional efforts (see the following chapters).

Figure 4.2: Earthwork as precondition for the track construction[15]

1) Earthwork of existing lines

2) Earthwork for new built / High Speed lines

Details about the construction and the embankments / cuttings are given in Schmied & Mottschall (2010). The following assumptions have been taken:

- foundation layer of gravel and sand (magnitude 40 cm)
- Width for renewal of existing lines: 6.60 m (single track) and 11.00 m (double track)
- Width for new built lines: 8.60 m (single track) and 13.30 m (double track)
- Density of gravel and sand: 2.80 t / m³

Table 4.1: Impact from the earthwork per km and year

	CO_2	**CED**	**PM_{10}**	**SO_2**	**NO_x**	**NMVOC**
	kg/y*km	MJ-equ/y*km	kg/y*km	kg/y*km	kg/y*km	kg/y*km
earthwork, single track renewal of existing lines	1'652	31'815	1.63	2.77	18.29	2.58
earthwork, double track renewal of existing lines	2'753	53'025	2.72	4.61	30.48	4.30
earthwork, single track new constructed lines	5'993	109'103	6	10	68	10
earthwork, double track new constructed lines	9'791	176'878	10.51	15.94	110.78	16.11
Sources : Schmied & Mottschall (2010), own calculations, assumed lifespan is 60 years						

[15] Images: 1) Aquasys (2011) 2) unknown

4.1.2 Bridges: viaduct, concrete bridge over a road and iron bridge

Three different types of bridges have been assessed: large bridges made of concrete for viaduct with a typical length of over 250m, smaller concrete bridges e.g. for crossing roads and other railway lines and iron bridges. The latter are most used for crossing waterways.

Figure 4.3: Assessed types of rail bridges: viaducts, smaller bridges and iron bridges[16]

Large viaducts, made of concrete (typical length > 200m)

Smaller bridges, made of concrete, e.g. crossing of roads

Iron bridges, mainly for crossing waterways

The construction of bridges reflects the average European conditions according to the available data from Schmied & Mottschall (2010). Included are the following processes:

- Construction material (e.g. per m of viaduct: 32.1 m^3 concrete, 3.51 t of steel and 26.17 m^3 of excavated earth)
- transport of the construction material to the construction site (concrete: 20km with lorry, steel: 300km with train),
- Energy for construction (8.4 Liter of Diesel per m bridge)

Table 4.2: Impact of bridges per km and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	kg/y*km	MJ-equ/y*km	kg/y*km	kg/y*km	kg/y*km	kg/y*km
viaduct, single track	154'925	1'485'081	154	183	319	60
viaduct, double track	258'209	2'475'135	256	305	532	100
small bridge, concrete, single track	67'534	646'981	67	80	139	26
small bridge, concrete, double track	112'557	1'078'302	112	133	232	44
iron bridge, single track	136'412	2'246'780	468	352	332	54
Iron bridge, double track	227'353	3'744'633	780	587	553	91
Sources : [Schmied & Mottschall], own calculations, assumed lifespan is 60 years						

[16] Images: 1) Bechtler (2006), 2) Aimaimyi (2008) & 3) DoubleH (2004)

4.1.3 Tunnel: mining and open-pit procedure

Two different types of tunnels have been assessed: mining and open-bit tunnels. A mined tunnel will be built by drilling / blasting and excavation of the material, respectively using a tunnel drilling machine. In the open-pit construction, the earth above is removed during the open construction and after completion backfilled. Both types differ in significant need for concrete and steel. If no further information is available, it is assumed that an average tunnel is created to 25% in open-pit and 75% in mining design (German average).

Figure 4.4: Assessed types of tunnels: mining and open pit tunnels[17]

1) Tunnel in mining construction

2) Tunnel in open-pit construction

The construction of the tunnels reflects average German conditions (average length of a tunnel: around 760 m), according to the detailed available data from Schmied & Mottschall (2010). The following processes are included:

- Construction material (e.g. per m of mined tunnel: 37.2 m^3 concrete, 1.6 t of steel and 128 m^3 of excavated material)
- transport of the construction material to the construction site (concrete: 20km with lorry, steel: 300km with train),
- Energy for construction (2.2 MWh electricity and 140 liter of Diesel for building machines per m of mined tunnel)

Assuming a European Electricity mix, the emission per kilometre of mined tunnel (double track) are about 51.7 t of CO_2, per km of open-pit tunnel 29.1 t of CO_2 and year.

Table 4.3: Impact of tunnels per km and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	t/y*km	GJ-equ/y*km	t/y*km	t/y*km	t/y*km	t/y*km
open pit, single track	285'351	3'037'296	434.02	422.09	639.60	103.98
open pit, double track	475'585	5'062'160	723.36	703.49	1'065.99	173.30
mining, single track	169'619	1'591'132	137	209	378	59
mining, double track	282'699	2'651'887	229	348	630	99
Sources : [Schmied & Mottschall], own calculations, assumed lifespan is 60 years						

[17] Images: 1) Cooper.ch (2006) 2) unknown

Sensitivity analysis for other electricity mixes in steel production

The construction of bridges as well as tunnels requires a considerable amount of steel. In the above modelling, a European electricity mix has been applied also to the steel production. The question raises, to what extend the result are changing by using local electricity mixes. In this section, the results are given for a steel production in Norway, Poland, Japan and Europe (Average).

Please note, that the production process[18] itself has not been changed, only the type of electricity.

Table 4.4: Sensitivity analysis of steel production with other electricity mixes

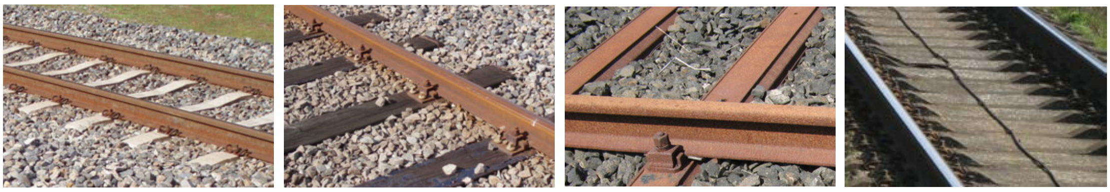
	Norway	**Poland**	**Japan**	**Europe**
Steel production	1 kg	1 kg	1 kg	1 kg
Electricity mix	100 % Hydro			
CO_2 Footprint per kWh of Electricity	0.009 kg CO_2	1.091 kg CO_2	0.524 kg CO_2	0.502 kg CO_2
CO_2 Footprint of steel production without electricity	1.868 kg CO_2	1.868 kg CO_2	1.868 kg CO_2	1.868 kg CO_2
CO_2 Footprint only of electricity for steel production	0.0002 kg CO_2	0.0239 kg CO_2	0.0115 kg CO_2	0.0110 kg CO_2
Grand Sum	**1.869 kg CO_2**	**1.892 CO_2**	**1.880 CO_2**	**1.879 CO_2**
Share of Electricity	0.01%	1.26%	0.61%	0.59%
Sources: ecoinvent 2.2, own calculations				

[18] The base of this comparison is the dataset "steel, converter, low-alloyed, at plant" of ecoinvent v2.2

4.1.4 Sleeper & Ballast: concrete, wood, iron and closed lane

Railway sleepers have been made traditionally of wood, but also concrete is now widely used. In total four different types of sleepers, resp. ballast has been assessed within this study: Wooden sleepers, Concrete sleepers, Iron sleepers, Closed lane or ballastless slab.

Figure 4.5: Assessed types of sleepers: concrete sleepers, wooden sleepers, iron sleepers and closed lane[19]



1) Concrete sleepers 2) Wooden sleepers 3) Iron sleepers 4) Closed lane

The material decomposition of the sleepers is taken from Schmied & Mottschall (2010). The following processes are included:

- Construction material (e.g. per concrete sleeper: 32.1 m^3 concrete, 3.51 t of steel and 26.17 m^3 of excavated earth)
- Transport to construction site over 300km and also for disposal

Table 4.5: Impact of sleeper and ballast per km and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	kg/y*km	MJ-equ/y*km	kg/y*km	kg/y*km	kg/y*km	kg/y*km
Concrete sleeper, single track	5'184	84'827	6.03	9.77	17.32	3.13
Concrete sleeper, double track)	10'340	169'058	12.02	19.48	34.53	6.23
Wooden sleeper, single track	6'328	337'382	17	18	23	17
Wooden sleeper, double track	12'699.23	675'774.38	33.47	35.63	46.00	33.99
Iron sleeper, single track	9'778.93	171'929.18	29.55	25.01	27.85	4.74
Iron sleeper, double track	19'700.15	347'212.78	59.22	50.38	56.42	9.59
Ballastless slab, single track	11'285.45	118'160.77	9.96	14.97	26.56	4.63
Ballastless slab, double track	22'166.12	226'406.92	18.99	28.92	52.18	8.81

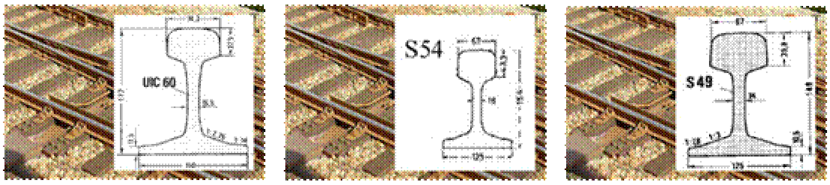
Sources : [Schmied & Mottschall], own calculations
The assumed lifespan is 35 years for concrete sleepers, 30 years for wooden and iron sleepers and 60 years for ballastless slab. Please note that the impact of rail is not included in this table.

[19] Images: 1) & 2) LooiNL (2007), 3) Dammseher (2009) and 4) Kohring (2007)

4.1.5 Rail: UIC 60, S54 and S49

The rail is one of the most important parts of the track itself: today all rails are made of high quality steel alloy. In general, the weight of the rail determines the type of track: The heavier the rails, the faster (and heavier) the trains running can be. In this study, three different rail types (of Germany) have been distinguished: UIC 60, S49 and S54. (The number stands for the weight in kg per m of rail).

Figure 4.6: Assessed types of rails: UIC60, S54 and S49[20]



1) UIC60 2) S54 3) S49

The profile of S49 was mainly in use for older regional and narrow-gauge tracks in Germany, while the rail profile of S54 can be found on main lines and especially station tracks. The heavier UIC profile is used since the early seventies for heavily loaded and high speed lines.

Table 4.6: Impact of rail per km and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	t/y*km	GJ-equ/y*km	t/y*km	t/y*km	t/y*km	t/y*km
Rail UIC 60, single track	6'090	96'974	18.29	13.43	13.80	2.18
Rail UIC 60, double track	12'180	193'948	36.58	26.87	27.60	4.37
Rail S49, single track	4'983	79'350	15	11	11	2
Rail S49, double track	9'976	158'859	29.96	22.01	22.61	3.58
Rail S54, single track	5'562	88'584	16.81	12.32	12.58	1.99
Rail S54, double track	11'109	176'926	33.58	24.61	25.12	3.98
Sources : [Schmied & Mottschall], own calculations, the assumed lifespan is 30 years						

[20] Images from Wikimedia (LooiNL, 2007) and own modifications

4.1.6 Mast, catenaries and overhead wiring

Electric locomotives and railcars collect the current from the overhead system; it consists of the mast (concrete or iron), the catenaries and the overhead wiring itself. Additionally some devices for line tensioning are also needed, however, in this study these extra items are not considered.

Figure 4.7: Assessed types of overhead system: Mast, Catenary and overhead wiring[21]

1) Wire of Cantenary incl. Overhead wiring

2) Mast (Concrete or Iron)

3) only overhead wiring

Table 4.7: Impact of mast, catenary and overhead wiring per km and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	t/y*km	GJ-equ/y*km	t/y*km	t/y*km	t/y*km	t/y*km
Wire of catenary, single track	353	6'938	3.91	18.46	4.04	0.70
Wire of catenary, double track	706	13'875	7.83	36.91	8.08	1.41
mast & overhead wiring, concrete, single track	1'367	23'578	3.02	3.82	3.04	0.68
mast & overhead wiring, concrete, double track	2'734	47'155	6.05	7.63	6.08	1.36
mast & overhead wiring, iron, single track	1'235	21'974	3.14	3.57	2.83	0.60
mast & overhead wiring, iron, double track	2'469	43'948	6.28	7.14	5.65	1.20
overhead wiring, single track, tunnel	536	10'413	0.96	1.97	1.16	0.21
overhead wiring, double track, tunnel	1'071	20'826	1.93	3.94	2.32	0.41
Sources : [Schmied & Mottschall], own calculations, assumed lifespan is 10 years for the overhead wiring and 60 years for the mast						

[21] Images: 1) chelseagirl (2006) 2) AlexHe34 (2010) 3) DBZ2313 (2010)

4.1.7 Signalisation & communication

For the safe operation of the rail track, signalling and communication is essential. In principle, the track is divided into individual sections (known as block section), in which a train can only enter if the section is free. The release is carried by signals that are usually controlled by the rail control centre. Within this study, we do not consider the electronic solutions for new built lines, e.g. the use of ETCS of high speed lines.

Figure 4.8: Assessed types of signalization and communication[22]

1) Signals & Cable for telecommunication

2) Cable drain

3) Building for Rail Control Center

Table 4.8: Impact of Signals and communication per km and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	kg/y*km	MJ-equ/y*km	kg/y*km	kg/y*km	kg/y*km	kg/y*km
Signals (per km single track)	33	548	0.09	0.08	0.08	0.02
Signals (per km double track)	56	914	0.14	0.13	0.14	0.03
cable for telecommunication (per km single track)	380	11'632	3	14	3	1
cable for telecommunication (per km double track)	634.47	19'400.90	4.38	23.48	5.26	1.51
cable drain (per km single track)	295.21	2'634.42	0.07	0.23	0.68	0.16
cable drain (per km double track)	491.81	4'388.95	0.12	0.38	1.13	0.26
Railway control centre, building	226.96	3'886.42	0.62	0.54	0.51	0.14
Railway control centre, electrical installations	965.43	20'254.63	3.05	5.48	2.78	0.83
Sources : [Schmied & Mottschall], own calculations The assumed lifespan is 30 years for signals and cable and 60 years for the Railway control centers.						

[22] Images: 1) Nominativus (2009) 2) Knörr (2009) 3) Swan (2009)

4.1.8 Construction and maintenance of relevant buildings

The system of rail needs some buildings for the entering / leaving of passengers, the maintenance of trains and the control of the network. Furthermore, for the transformation and distribution of electricity some buildings are also needed. Please note that in other studies about traffic comparisons[23] the buildings are not included. As a detailed analysis of all buildings is not possible, the rough assumptions of Schmied & Mottschall (2010) for classifying the buildings are used:

- Railway station: Junction for intercity trains (3 floors, 29'000 m^2 area for access to trains, 20'000 m^2 inside)
- Stop for local trains (1-2 floors, 2'000 m^2 area for access to trains, 600 m^2 area inside)
- Stop for Freight trains
- Site for maintenance / repairing
- Transformer Substation: Building and Electrical Installations

Figure 4.9: Assessed types of buildings: concrete sleepers, wooden sleepers, iron sleepers and closed lane[24]

1) Junction for intercity trains and local trains
2) Stop for local trains Stop for freight trains
3) Site for maintenance / reparing
4) Transformator and electrical Installations

Table 4.9: Impact from the construction and maintenance of railway buildings, per unit and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	kg/y*unit	MJ-equ/y*unit	kg/y*unit	kg/y*unit	kg/y*unit	kg/y*unit
Junction for intercity trains	164'714	1'310'519	115	165	310	54
Junction for local trains	68'142	539'044	47	68	128	22
Stop for local trains	10'407	81'429	7	10	20	3
Railway station (stop for freight trains)	156'005	1'283'304	113	159	311	55
Site for maintenance / reparing	122'083	686'672	22	78	215	31
Transformer Substation: Building	642	6'482	0	1	1	0
Transformer Substation: Electrical Installations	4'901	86'222	31	114	29	5
Sources : [Schmied & Mottschall], own calculations, assumed lifespan is 60 years						

[23] e.g. www.mobitool.ch or Spielmann et al. (2007)

[24] Images: 1) Aepli (2009), 2) Andy F (2009), 3) & 4) Tuchschmid 2010

4.2 Construction and maintenance of trains

The rolling stock is one of the most visible elements of a railway system. The impact calculation is based on the data cited in Spielmann et al. (2007), four different train types has been analysed[25]. In difference to the Ecoinvent-data, the impact of the train construction and maintenance is expressed in relation to the transport performance of gross tonne kilometre. It is therefore assumed that a train with the double weight also has the double impact. The reason of this calculation is the different load-factors and train lengths in different countries. The following assumptions have been made:

- Local Train: 171t, 40y lifespan, Transport performance: 150’000 km / a
- Intercity Train: 317 t, 40y lifespan, Transport performance: 500’000 km /a
- High-speed Train: 664 t, 40y lifespan, Transport performance: 150’000 km / a
- Freight Train: 1 Locomotive (85t) & 20 Waggons (22t), 37% load factor of 58t per Waggon = 429t of freight, total 953t, 40y lifespan, Transport performance: 40’000 km /a

Figure 4.10: Assessed types of trains: Regional trains, intercity trains and freight trains[26]

1) Local trains

2) Intercity trains

3) Freight train

Table 4.10: Impact from the construction and maintenance of trains, per unit and year

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	kg/y*unit	MJ-equ/y*unit	kg/y*unit	kg/y*unit	kg/y*unit	kg/y*unit
Regional train	8'982	234'488	17.01	42.31	24.08	9.60
Long distance train	60'463	1'513'825	61.00	212.87	124.89	125.41
High Speed train	95'768	1'998'890	78.7	252.5	172.5	144.6
Freight train	23'756	459'685	54.83	80.00	55.48	16.14

Table 4.11: Impact from the construction and maintenance of trains, per Gtkm passenger train

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	g/Gtkm	J-equ/Gtkm	mg/Gtkm	mg/Gtkm	mg/Gtkm	mg/Gtkm
Regional train	0.350	9.142	0.663	1.650	0.939	0.374
Long distance train	0.381	9.551	0.385	1.343	0.788	0.791
High Speed train	0.288	6.021	0.237	0.761	0.520	0.435
Freight train	0.623	12.059	1.438	2.099	1.456	0.423

[25] For the calculation of the different countries, half local train and half long-distance-train has been assumed.

[26] Images: 1) Gubler (2007) 2) Gubler (2008), 3) Knörr (2007)

4.3 Train operation and energy provision for building

All trains and buildings need energy for the operation. The phase of operation has been subject of analysis in the past; also the existing tools of EcoPassanger and EcoTransIT have focused on this part. For most of the countries and environmental impact categories, the operation phase is still the most important one.

Figure 4.11: Assessed types of energy: electricity, Natural Gas and oil[27]


1) electricity


2) Natural gas for heat


3) Oil for heat

Within this study, the same approach as for the mentioned tools has been used: The impact factors stems from Ecoinvent, the consumed energy has been taken from UIC (2009) or the UIC Energy and CO_2 database. For the electricity provision of the trains and the buildings, the following energy carriers have been assessed: hard coal, lignite, natural gas, oil, nuclear, hydropower, wind power. For the heating of the building also oil[28] and natural gas have been analysed.

Table 4.12: Impact from the energy provision per kWh used energy

	CO_2	CED	PM_{10}	SO_2	NO_x	NMVOC
	g/kWh	J-equ/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh
Heavy fuel oil	334.5	5093.9	172.2	1896.2	540.5	151.0
Natural gas	242.2	4518.5	6.3	95.0	159.2	100.3
electricity, hard coal, at power plant	968.5	12799.8	82.9	909.8	980.9	65.1
electricity, lignite, at power plant	1203.4	12805.9	71.4	631.5	835.2	30.7
electricity, natural gas, at power plant	525.2	10190.5	12.6	301.0	501.5	311.3
electricity, oil, at power plant	856.4	12241.6	196.8	6704.9	2771.9	381.9
electricity, nuclear, at power plant	8.7	11655.9	40.1	37.2	31.3	6.5
electricity, hydropower, at power plant	3.8	3837.5	15.7	5.7	13.9	2.5
electricity, at wind power plant	10.3	4050.6	20.2	32.3	24.2	6.5

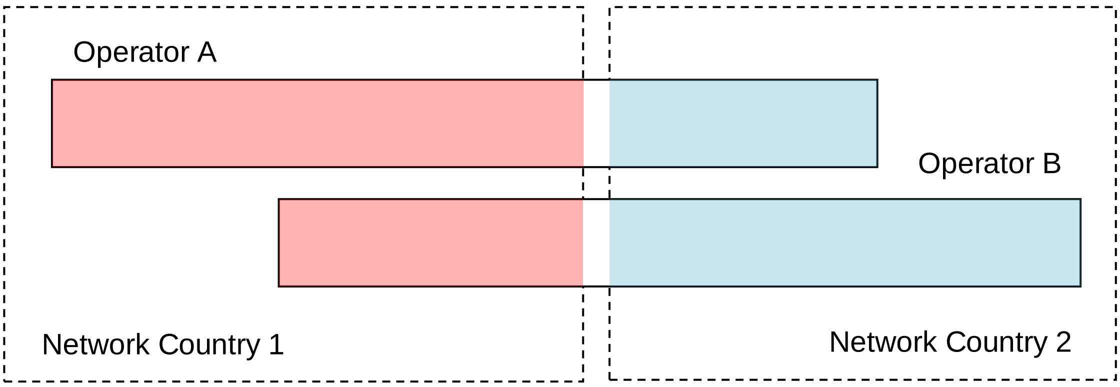
[27] Images: 1) Calson2 (2007) 2) Kelle (2010) 3) Flcelloguy(2007)

[28] The two data sets « heat, heavy fuel oil, at industrial furnace 1MW" and "heat, natural gas, at industrial furnace >100kW" have been used.

5 Relevance of rail infrastructure in several European countries

The modules described above are combined to estimate the impact of the railway infrastructure of a specific country. The combination has been done according to the described methodology in section 3.2.1. Enhanced data from UIC-statistic (2009), sent out questionnaires and information from experts have been needed to estimate the impact of national railways. Please note the difference between the transport performance of an operator on the national territory (e.g. Operator A, equal in this case to the national network Country 1, red marked area) and the total transport performance of the operator (blue and red area of Operator A).[29] Due to the limited data availability and different statistics, it is possible that not verified values have been used in this study. The reader may then correct the values himself in the embedded calculator and calculate the correct impact of rail infrastructure.

Figure 5.1



On the next pages, input data and results of the environmental impact due to the railway infrastructure for seven countries are specified. More detailed factsheets of the calculation are available in the annex.

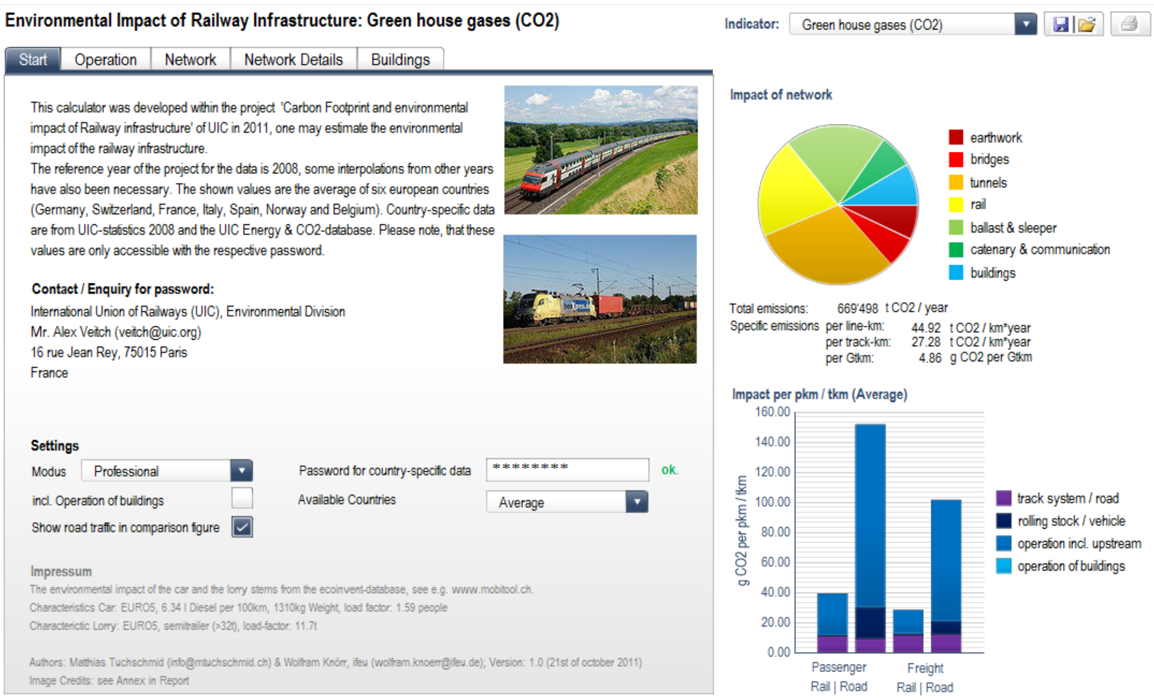
5.1 Embedded Calculator / Online-Calculator

All the input data and as well the results are available in the embedded calculator of the project (Powerpoint-Presentation) alternatively the calculator is available from www.mtuchschmid.ch/uic-infrastructure[30]. Within the calculator one may also change factors and parameters and estimate the impact of certain policy changes.

[29] The UIC Energy and CO2-database do not distinguish between different operators, in UIC-statistics the transport performance in gross tonne kilometre is available for the whole operator (incl. other countries), while the figures for pkm and tkm are only available for national territories. However in this study the traffic on the national territory of all operators is the focus (red areas of Country 1). In Switzerland and Italy the average value of 2.16 Gtkm / tkm has been used to determine the transport performance.

[30] The password is „himalaya“

Figure 5.2: Online Calculator for the determination of the environmental impact of railway infrastructure



Within the Online-Calculator the user has to choose the mode according to his needs:

- Easy-Mode: One gets a quick image of the influence of the railway infrastructure, furthermore the parameter of the operation-phase can be adapted to real situations.
- Professional-Mode: Within this mode, the user has access to all parameters and can adapt a certain network or specific line according to his needs. Please note the button right above to save / load user-specified scenarios. These scenarios are not transferable to another computer, the data input stays on the same computer.

If you are a member of the UIC-Energy and CO2-database, you may have access to the also stored country specific data in the tool (Germany, Switzerland, France, Italy, Spain, Norway, Belgium, Japan and India). Please ask in these cases the given resource person from the starting page for the password.

5.2 Country specific networks

5.2.1 Germany

In the year 2008, total 33'855 km of rail lines are in use, 66'634 million passengers kilometres have been transported every year. The quality of the data can be considered as very good, as no assumption or estimations have been required. Table 5.1 shows the main input data for the calculation; Table 5.2 gives the result for CO_2. Other indicators can be analysed in the online calculator (see section 5.1).

Table 5.1: Data for Germany

	Value	Remarks & Sources
Network in Germany		
Length of network (lines in operation) in km	33'855	UIC-Statistics 2008
Share of lines (single | double)	47% | 53%	UIC-Statistics 2008
Length of network (Track length) in km	64'105	UIC-Statistics 2008
Share of bridges / tunnels / normal track	1.8% | 1.3% | 96.9%	Schmied & Mottschall (2010)
Operation of Trains		
Transport performance in million pkm (Passenger)	66'634	UIC-Statistics 2008
Transport performance in million tkm (Freight)	114'569	UIC Energy and CO2 database
Electricity mix for trains (fossil | nuclear | hydro & renewable)	58.1% | 25.9% | 16.0%	IEA
Electricity for Traction in GWh (Passengers | Freight)	6'678 | 3'187	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	225 | 254	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	8% | 58% | 34%	Schmied & Mottschall (2010)
Share of track profiles (UIC60 | S54 | S49)	41% | 23% | 36%	Schmied & Mottschall (2010)
Share of sleeper (concrete | wood | iron | ballastless slab)	75% | 16% | 7% | 2%	Schmied & Mottschall (2010)
Share of tunneltype (open pit | mining)	25% | 75%	Schmied & Mottschall (2010)
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	20 | 279 | 4'883 | 297	Schmied & Mottschall (2010)
Sites for Maintenance	107	Schmied & Mottschall (2010)

Table 5.2: Carbon Footprint of Rail in Germany

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	1'353'657
CO_2-Emissions in tonnes per year (per km of line | per km of track)	40.0 | 21.1
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	8.6 | 6.8
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	63.9 | 21.0
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	1.0 | 1.4
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**73.5 | 29.2**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*7.1 | 5.7*

The results of this study are in the same range of magnitude as the data of Schmied & Mottschall (2010), but are not identical (although the same data and emission factors have been used). The main reason of these differences lies in the chosen approach: Schmied & Mottschall calculated first the carbon impact of each subsection and aggregated then an average impact factor. This study calculated first the overall impact and then the impact per passenger kilometre.

Bottom up vs. Top-down?

The calculation of the carbon footprint differs between the two approaches „top-down“and „bottom-up“. The reasons are the different emission factors per track and the respective shares. An example:

- Line 1: many bridges and tunnels (100 t CO_2 / y*km), mainly freight and regional traffic
- Line 2: flat area without obstacles (15 t CO_2/y*km), mainly intercity traffic

Table 5.3: Bottom up vs. Top-down: Example of a rail network

			Freight		**Intercity**		**Regional**		**Total**	
	t/y	[km]	[mio. Gtkm]		[mio. Gtkm]		[mio. Gtkm]		[mio. Gtkm]	
Line 1	1000	10	100	*56%*	20	*11%*	60	*33%*	180	*100%*
Line 2	150	10	10	*5%*	150	*79%*	30	*16%*	190	*100%*
Network	1150	20	110	30%	170	46%	90	24%	370	100%

If we calculate now from the bottom we got the typical emission factors between 1.4 g CO_2 per Gtkm and 5.1 g CO_2 per Gtkm.

Freight: 56% * 1000t + 5% * 150t = 563t 563t / 110 Mio. Gtkm = **5.1 g / Gtkm**

Intercity: 11% * 1000t + 79% * 150t = 230t 230t / 170 Mio. Gtkm = **1.4 g / Gtkm**

Regional: 33% * 1000t + 16% * 150t = 357t 357t / 90 Mio. Gtkm = **4.0 g / Gtkm**

The top-down approach is calculated fast: The overall emissions of 1150 t / y divided by the total transport performance of 270 Mio. Gtkm results in the specific emission of 3.1 g CO_2 per Gtkm. The more specific data is available, the more accurate emission can be calculated. Due to the poor data availability, this study calculated the impact from rail infrastructure with the top-down approach.

5.2.2 Switzerland

In the year 2008, total 3'051 km of rail lines are in use, 7'377 million passengers kilometres have been transported every year. The quality of the data is considered to be okay, assumption have been necessary for some additional data. Please note, that the operation of the buildings is estimated based on German consumption figures.

Table 5.4: Data for Switzerland

	Value	Remarks & Sources
Network in Switzerland		
Length of network (lines in operation) in km	3'051	UIC-Statistics 2008
Share of lines (single | double)	44% | 56%	UIC-Statistics 2008
Length of network (Track length) in km	7'377	UIC-Statistics 2008
Share of bridges / tunnels / normal track	1.9% | 5.4% | 92.8%	Personal Communication
Operation of Trains		
Transport performance in million pkm (Passenger)	16'182	UIC-Statistics 2008
Transport performance in million tkm (Freight)	4'181	UIC-Statistics 2008
Electricity mix for trains (fossil | nuclear | hydro & renewable)	0.0% | 25.0% | 75.0%	IEA
Electricity for Traction in GWh (Passengers | Freight)	1'251 | 470	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	0 | 6	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	8% | 58% | 34%	Assumption: same as Germany
Share of track profiles (UIC60 | S54 | S49)	41% | 23% | 36%	Assumption: same as Germany
Share of sleeper (concrete | wood | iron | ballastless slab)	75% | 16% | 7% | 2%	Assumption: same as Germany
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	2 | 25 | 442 | 27	Estimation: same Nr. of building / km track as in DE)
Sites for Maintenance	10	Estimation: same Nr. of building /

Table 5.5 Carbon Footprint of Rail in Switzerland

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	210'517
CO_2-Emissions in tonnes per year (per km of line | per km of track)	69.0 | 28.5
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	8.5 | 6.7
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	0.4 | 4.5
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	1.0 | 1.3
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**9.9 | 12.5**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*5.2 | 4.1*

Higher Lifespan of bridges and tunnels?

In PCR for Railways (EPD, 2009) a lifespan of 60 years for civil engineering constructions as bridges, tunnels, viaducts and stations is declared. However, the railway in Switzerland has started more than 150 years ago and several bridges and tunnels are older than 60 years. As a sensitivity analysis, one finds the calculations of this study with a higher lifespan of 100 years instead of the 60 years (used in this study) in the table below.

The emissions from the network and the buildings are reduced from 8.5 g to 6.7g per pkm (-21%), the overall carbon footprint is reduced by 17%. As the operation phase is far more important in other countries, one may draw the conclusion that the question of lifespan is not of primary importance.

Table 5.6: Carbon footprint of rail in Switzerland with a lifespan of building and civil engineering constructions of 100 years instead of 60 years

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	166'652
CO_2-Emissions in tonnes per year (per km of line | per km of track)	54.6 | 22.6
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	6.7 | 5.3
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	0.4 | 4.5
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	1.0 | 1.3
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**8.1 | 11.1**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*5.2 | 4.1*

5.2.3 France

In the year 2008, total 29’901 km of rail lines are in use, 85’694 million passengers kilometres have been transported every year. The quality of the data can be considered as ok, however, many assumptions were required. Please note that the operation of the buildings is estimated (based on German consumption figures).

Table 5.7: Data for France

	Value	Remarks & Sources
Network in France		
Length of network (lines in operation) in km	29'901	UIC-Statistics 2008
Share of lines (single | double)	43% | 57%	UIC-Statistics 2008
Length of network (Track length) in km	47'842	UIC-Statistics 2008
Share of bridges / tunnels / normal track	1.9% | 5.4% | 92.8%	Assumption: same as CH
Operation of Trains		
Transport performance in million pkm (Passenger)	85'697	UIC-Statistics 2008
Transport performance in million tkm (Freight)	26'482	UIC-Statistics 2008
Electricity mix for trains (fossil | nuclear | hydro & renewable)	10.0% | 90.0% | 0.0%	IEA
Electricity for Traction in GWh (Passengers | Freight)	6'500 | 1'543	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	137 | 57	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	8% | 58% | 34%	Assumption: same as Germany
Share of track profiles (UIC60 | S54 | S49)	41% | 23% | 36%	Assumption: same as Germany
Share of sleeper (concrete | wood | iron | ballastless slab)	75% | 16% | 7% | 2%	Assumption: same as Germany
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	34 | 318 | 2'668 | 104	Personal Communication
Sites for Maintenance	46	Personal Communication

Table 5.8: Carbon Footprint of Rail in France

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	1'343'847
CO_2-Emissions in tonnes per year (per km of line | per km of track)	44.9 | 28.1
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	11.0 | 15.0
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	11.2 | 11.0
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	0.7 | 1.5
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**22.9 | 27.5**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*5.2 | 7.1*

5.2.4 Italy

In the year 2008, total 16'529 km of rail lines are in use, 45'767 million passengers kilometres have been transported every year. The quality of the data can be considered as fair, some estimation were required. Please note that the operation of the buildings is estimated based on German consumption figures.

Table 5.9: Data for Italy

	Value	Remarks & Sources
Network in Italy		
Length of network (lines in operation) in km	16'529	UIC-Statistics 2008
Share of lines (single | double)	56% | 44%	UIC-Statistics 2008
Length of network (Track length) in km	23'835	UIC-Statistics 2008
Share of bridges / tunnels / normal track	3.3% | 8.5% | 88.2%	Questionnaire
Operation of Trains		
Transport performance in million pkm (Passenger)	45'767	UIC-Statistics 2008
Transport performance in million tkm (Freight)	22'116	UIC Energy and CO2 database
Electricity mix for trains (fossil | nuclear | hydro & renewable)	65.7% | 0.0% | 34.3%	IEA
Electricity for Traction in GWh (Passengers | Freight)	3'792 | 793	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	80 | 9	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	8% | 58% | 34%	Assumption: same as Germany
Share of track profiles (UIC60 | S54 | S49)	41% | 23% | 36%	Assumption: same as Germany
Share of sleeper (concrete | wood | iron | ballastless slab)	75% | 16% | 7% | 2%	Assumption: same as Germany
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	10 | 137 | 2'394 | 145	Estimation: same Nr. of building / km track as in DE)
Sites for Maintenance	52	Estimation: same Nr. of building / km track as in DE)

Table 5.10: Carbon Footprint of Rail in Italy

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	854'642
CO_2-Emissions in tonnes per year (per km of line | per km of track)	51.7 | 35.9
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	12.1 | 16.3
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	54.5 | 22.7
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	0.6 | 1.3
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**67.2 | 40.3**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*5.9 | 8.0*

5.2.5 Spain

In the year 2008, total 11'801 km of rail lines are in use, 22'073 million passengers kilometres have been transported every year. The quality of the data can be considered as very good, as only one assumption (Share of tunnel type) was required.

Table 5.11: Data for Spain

	Value	Remarks & Sources
Network in Spain		
Length of network (lines in operation) in km	11'801	UIC-Statistics 2008
Share of lines (single | double)	73% | 27%	UIC-Statistics 2008
Length of network (Track length) in km	17'960	UIC-Statistics 2008
Share of bridges / tunnels / normal track	1.1% | 4.2% | 94.7%	Questionnaire
Operation of Trains		
Transport performance in million pkm (Passenger)	22'073	UIC-Statistics 2008
Transport performance in million tkm (Freight)	10'174	UIC-Statistics 2008
Electricity mix for trains (fossil | nuclear | hydro & renewable)	48.1% | 20.3% | 31.6%	IEA
Electricity for Traction in GWh (Passengers | Freight)	1'699 | 447	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	50 | 25	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	34% | 52% | 14%	Questionnaire
Share of track profiles (UIC60 | S54 | S49)	12% | 10% | 78%	Questionnaire
Share of sleeper (concrete | wood | iron | ballastless slab)	89% | 11% | 0% | 0%	Questionnaire
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	95 | 482 | 1'065 | 136	Questionnaire
Sites for Maintenance	38	Questionnaire

Table 5.12: Carbon Footprint of Rail in Spain

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	506'726
CO_2-Emissions in tonnes per year (per km of line | per km of track)	42.9 | 28.2
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	11.9 | 23.5
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	31.3 | 20.9
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	0.5 | 1.7
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**43.7 | 46.2**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*3.9 | 7.6*

5.2.6 Norway

In the year 2008, total 4'114 km of rail lines are in use, 3'080 million passengers kilometres have been transported every year. The quality of the data can be considered as very good. Almost all data has been provided by the Norwegian Railways in questionnaire, only the operation of the buildings is estimated based on German consumption figures.

Table 5.13: Data for Norway

	Value	Remarks & Sources
Network in Norway		
Length of network (lines in operation) in km	4'114	UIC-Statistics 2008
Share of lines (single | double)	94% | 6%	UIC-Statistics 2008
Length of network (Track length) in km	4'374	UIC-Statistics 2008
Share of bridges / tunnels / normal track	1.5% | 6.8% | 91.7%	Questionnaire
Operation of Trains		
Transport performance in million pkm (Passenger)	3'080	UIC-Statistics 2008
Transport performance in million tkm (Freight)	3'666	UIC Energy and CO2 database
Electricity mix for trains (fossil | nuclear | hydro & renewable)	0.0% | 0.0% | 100.0%	IEA
Electricity for Traction in GWh (Passengers | Freight)	336 | 144	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	0 | 5	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	0% | 60% | 40%	Questionnaire
Share of track profiles (UIC60 | S54 | S49)	3% | 17% | 81%	Questionnaire
Share of sleeper (concrete | wood | iron | ballastless slab)	80% | 20% | 0% | 0%	Questionnaire
Share of tunneltype (open pit | mining)	5% | 95%	Questionnaire
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	1 | 18 | 318 | 19	Questionnaire, Extrapolation
Sites for Maintenance	6	Questionnaire, Extrapolation

Table 5.14: Carbon Footprint of Rail in Norway

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	128'791
CO_2-Emissions in tonnes per year (per km of line | per km of track)	31.3 | 29.4
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	20.7 | 17.8
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	0.4 | 3.9
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	0.9 | 1.3
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**22.1 | 23.1**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*12.4 | 10.5*

5.2.7 Belgium

In the year 2008, total 3’513 km of rail lines are in use, 10’404 million passengers kilometres have been transported every year. The quality of the data can be considered as fair, some estimation were required. Please note that the operation of the buildings is estimated based on German consumption figures.

Table 5.15: Data for Belgium

	Value	Remarks & Sources
Network in Belgium		
Length of network (lines in operation) in km	3'513	UIC-Statistics 2008
Share of lines (single | double)	12% | 88%	UIC-Statistics 2008
Length of network (Track length) in km	6'283	UIC-Statistics 2008
Share of bridges / tunnels / normal track	2.2% | 1.3% | 96.5%	Questionnaire
Operation of Trains		
Transport performance in million pkm (Passenger)	10'404	UIC-Statistics 2008
Transport performance in million tkm (Freight)	7'882	UIC Energy and CO2 database
Electricity mix for trains (fossil | nuclear | hydro & renewable)	39.6% | 58.4% | 2.0%	IEA
Electricity for Traction in GWh (Passengers | Freight)	1'083 | 324	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	11 | 26	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	26% | 57% | 17%	Questionnaire
Share of track profiles (UIC60 | S54 | S49)	37% | 63% | 0%	Questionnaire
Share of sleeper (concrete | wood | iron | ballastless slab)	77% | 23% | 0% | 0%	Questionnaire
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	2 | 29 | 509 | 31	Estimation: same Nr. of building / km track as in DE)
Sites for Maintenance	11	Estimation: same Nr. of building / km track as in DE)

Table 5.16: Carbon Footprint of Rail in Belgium

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	130'441
CO_2-Emissions in tonnes per year (per km of line | per km of track)	37.1 | 20.8
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	6.4 | 5.5
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	31.4 | 19.9
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	0.9 | 1.3
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**38.8 | 26.7**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*59.5 | 50.5*

5.2.8 Japan

In the year 2008, total 7'527 km of rail lines are in use, 235'455 million passengers kilometres have been transported every year. The quality of the data can be considered as fair, some estimation were required. Please note that the operation of the buildings is estimated based on German consumption figures. No energy consumption figures for freight traffic are available, so only passenger traffic was assessed.

Table 5.17: Data for Japan

	Value	Remarks & Sources
Network in Japan		
Length of network (lines in operation) in km	7'527	UIC-Statistics 2008
Share of lines (single | double)	0% | 32%	UIC-Statistics 2008
Length of network (Track length) in km	11'195	UIC-Statistics 2008
Share of bridges / tunnels / normal track	14.2% | 5.5% | 80.3%	Questionnaire
Operation of Trains		
Transport performance in million pkm (Passenger)	253'555	UIC-Statistics 2008
Transport performance in million tkm (Freight)	22'100	UIC-Statistics 2008
Electricity mix for trains (fossil | nuclear | hydro & renewable)	36.0% | 43.0% | 21.0%	IEA
Electricity for Traction in GWh (Passengers | Freight)	9'375 | 00	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	135 | 0	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	62% | 19% | 19%	Questionnaire
Share of track profiles (UIC60 | S54 | S49)	41% | 23% | 36%	Assumption: same as Germany
Share of sleeper (concrete | wood | iron | ballastless slab)	60% | 26% | 0% | 14%	Assumption: same as Germany
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	6 | 70 | 1'629 | 253	Questionnaire
Sites for Maintenance	0	Questionnaire

Table 5.18: Carbon Footprint of Rail in Japan

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	540'753
CO_2-Emissions in tonnes per year (per km of line | per km of track)	71.8 | 48.3
CO_2-Emissions in g (Passenger: per pkm)	2.3
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm)	11.5
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm) | Freight: per tkm)	0.1
Emissions in g of CO_2 (Passenger: pkm	**13.9**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm)	*0.8*

5.2.9 India

In the year 2008, total 63'810 km of rail lines are in use, 769'956 million passengers kilometres have been transported every year. The quality of the data can be considered as weak, some estimation were required. Additionally, the railway in India is different from the European railways; the high load factors reduce the impact per passenger kilometre significantly. Please note that the operation of the buildings is estimated (based on German consumption figures).

Table 5.19: Data for India

	Value	Remarks & Sources
Network in India		
Length of network (lines in operation) in km	63'810	UIC-Statistics 2008
Share of lines (single | double)	71% | 29%	UIC-Statistics 2008
Length of network (Track length) in km	111'599	UIC-Statistics 2008
Share of bridges / tunnels / normal track	1.8% | 1.3% | 96.9%	Assumption: Same as DE
Operation of Trains		
Transport performance in million pkm (Passenger)	769'956	UIC-Statistics 2008
Transport performance in million tkm (Freight)	521'371	UIC-Statistics 2008
Electricity mix for trains (fossil | nuclear | hydro & renewable)	82.6% | 1.8% | 15.7%	IEA
Electricity for Traction in GWh (Passengers | Freight)	4'195 | 4'248	Questionnaire
Diesel for Traction in 1000 tonnes (Passengers | Freight)	1088 | 930	Questionnaire
Additional data		
Share of viaduct / concrete bridges / iron bridges	8% | 58% | 34%	Assumption: same as Germany
Share of track profiles (UIC60 | S54 | S49)	41% | 23% | 36%	Assumption: same as Germany
Share of sleeper (concrete | wood | iron | ballastless slab)	75% | 16% | 7% | 2%	Assumption: same as Germany
Share of tunneltype (open pit | mining)	25% | 75%	Assumption: same as Germany
Railway stations (Intercity Junction | Local Junction | Local Stop | Freight)	38 | 528 | 9'242 | 560	Estimation: same Nr. of building / km track as in DE)
Sites for Maintenance	203	Estimation: same Nr. of building /

Table 5.20: Carbon Footprint of Rail in India

	Value
Emission from construction of network & buildings	
CO_2-Emissions in tonnes per year	2'329'679
CO_2-Emissions in tonnes per year (per km of line | per km of track)	36.5 | 20.9
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	1.1 | 2.9
Emission from operation of train	
CO_2-Emissions in g for train (Passenger: pkm | Freight: tkm)	7.8 | 10.7
Emission from train production & maintenance	
CO_2-Emissions in g (Passenger: per pkm | Freight: per tkm)	0.2 | 1.1
Emissions in g of CO_2 (Passenger: pkm | Freight: tkm)	**9.1 | 14.8**
estimated additional CO_2-Emissions for operation of buildings (Passenger: g per pkm | Freight: g per tkm)	*0.9 | 2.4*

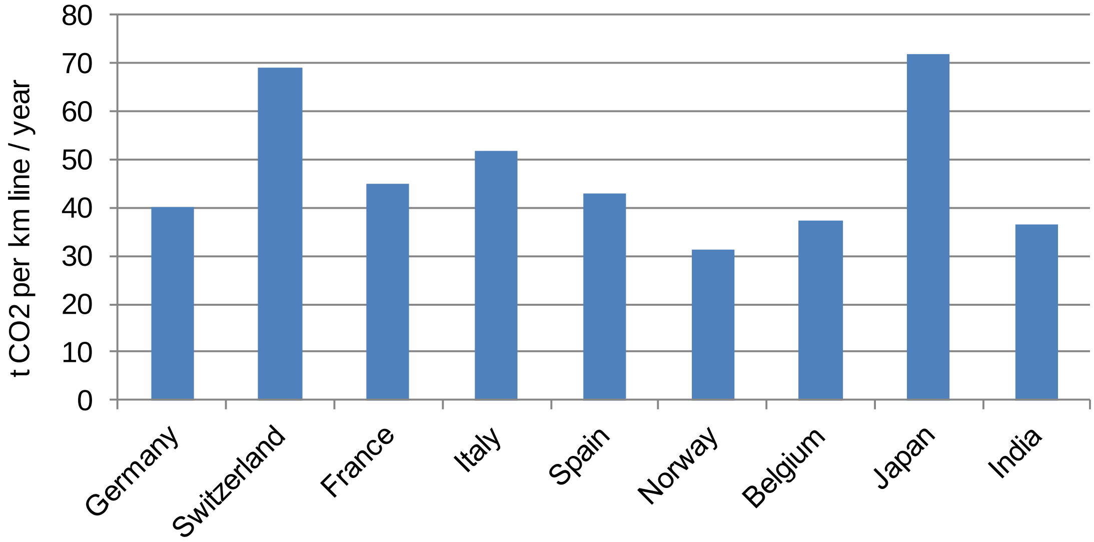
5.3 Overview and Comparison

Although an analysis of the other indicators is possible, only CO_2 as main indicator was used to draw some conclusions. Furthermore, the focus is set on the passenger traffic.

5.3.1 Carbon Footprint of rail infrastructure per km of line.

The carbon footprint of the analysed rail network differ considerably: While in Norway the carbon Footprint is 32.8 t CO_2 per km of line, the network in Japan emits more than 71 t of CO_2 per km of line and year. The main factors are the share of bridges and tunnels and the share of double tracks. As a weighted average of the considered countries, 42 t of CO_2 are emitted per km of line and year.

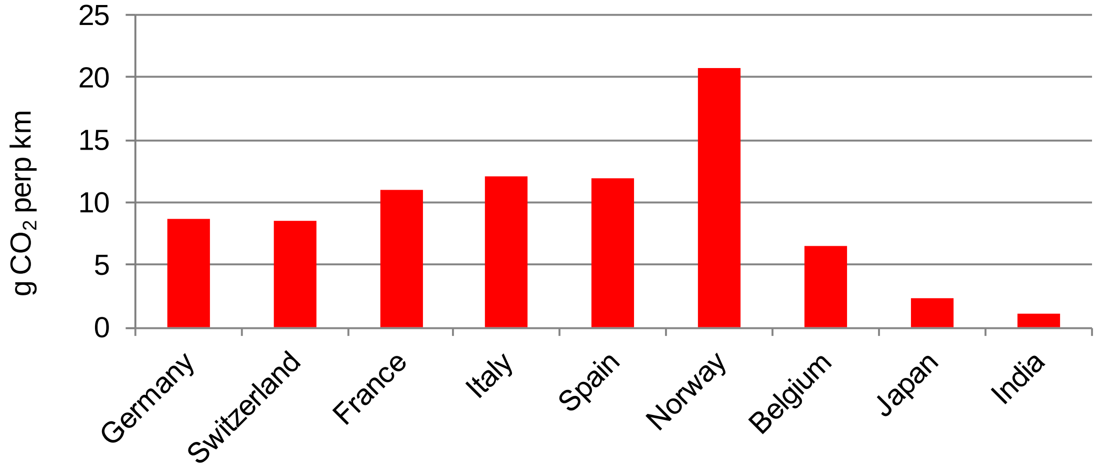
Figure 5.3: Carbon Footprint per km of line and year



5.3.2 Carbon Footprint of rail infrastructure per pkm

The carbon footprint per passenger kilometre mainly depends on the emission per km of line, the number and weight of trains and the load factor of the trains. Especially the example of Japan shows the importance of a high transport performance: As the Carbon Footprint per km of line and year is the highest in Japan, the impact per km is rather small with 2.3 g of CO_2. The reason is on the one hand the dense traffic on the lines (257 daily trains per km of line) and the high number of passengers per train (359 Passenger) on the other.

Figure 5.4: Carbon Footprint per passenger kilometre



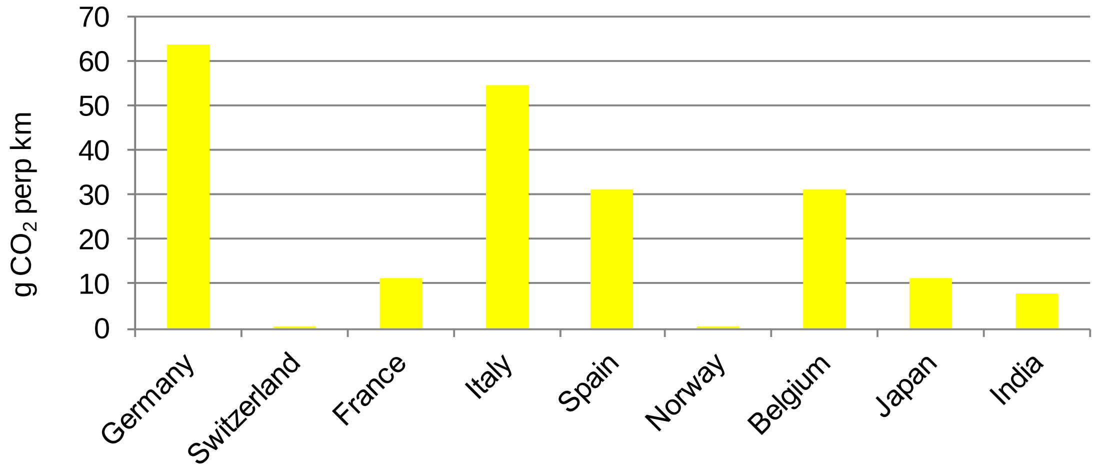
5.3.3 Carbon footprint of rolling stock

The impact of the rolling stock is considerably low (between 0.15 and 1.05 g per pkm). The most important factors are the load factor and the number of seats per ton of train (see also Figure 6.1)

5.3.4 Carbon footprint of Operation

The impact of the operation is well-known (Knörr, 2008a, 2008b) and also subject of the current UIC-Tools “EcoPassenger” and “EcoTransIT”. The carbon footprint depends on the share of electrified lines, the electricity mix and the specific energy consumption per passenger kilometre (which depends on the train specific consumption, the load factors and the success of the energy efficiency programs of the railways).

Figure 5.5: Carbon Footprint of the train operation in selected countries



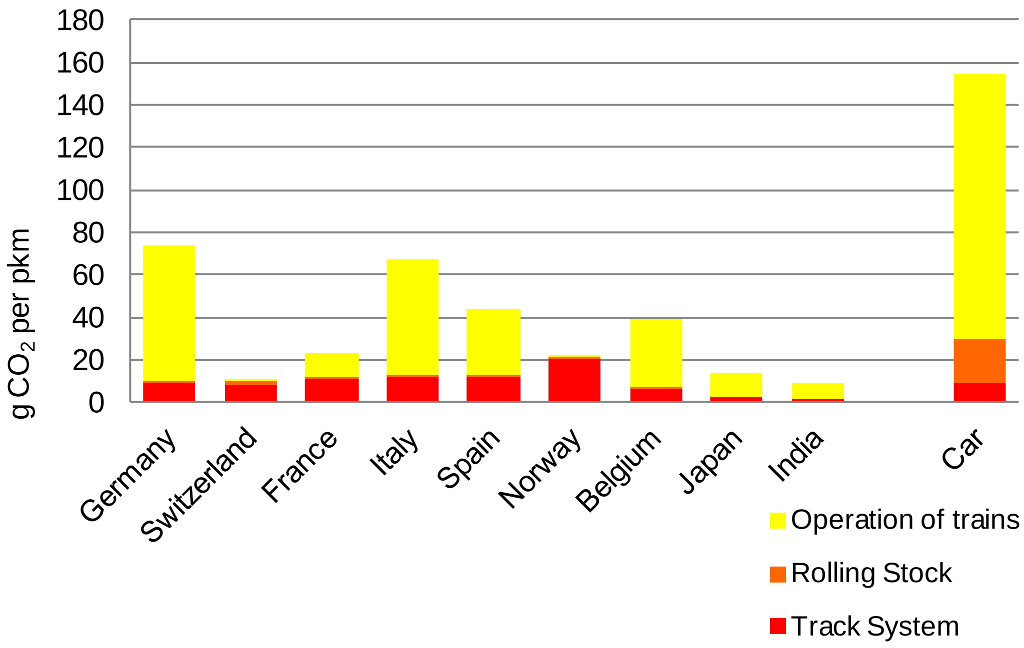
6 Summary & Recommendations

In this study a transparent and comprehensive methodology for the estimation of carbon footprint and other environmental impacts of rail infrastructure was developed. This methodology can be used for single lines as well as for networks in countries. The quality of results depends from the available data quality as well as the granularity of the available data: Bottom-up calculations (for each line) produce more precise results than top-down calculations (e.g. country average from UIC-statistics, see also section 5.2)

6.1 Share of rail infrastructure

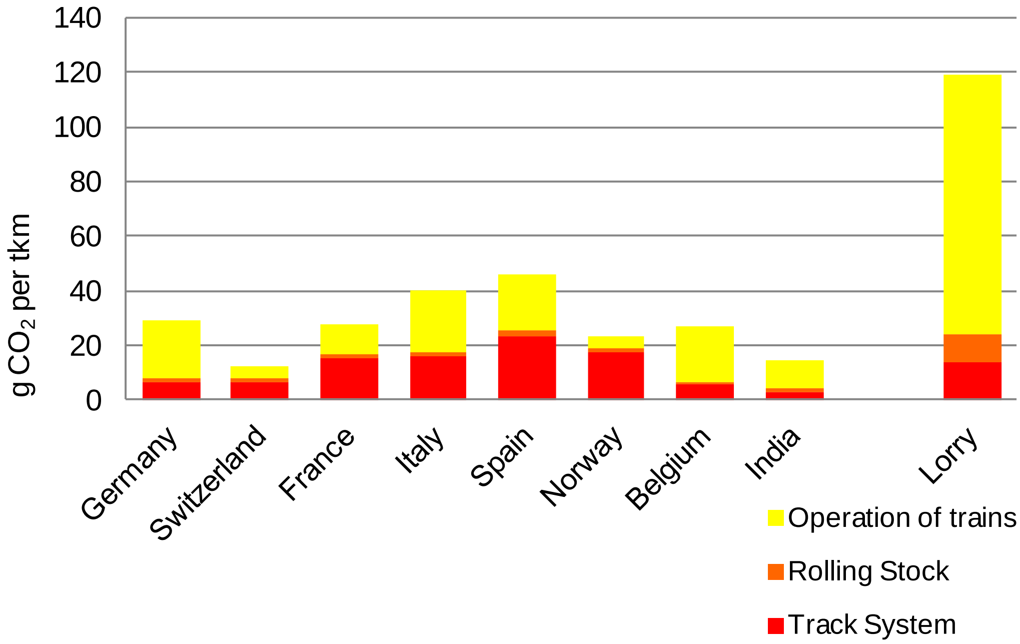
The track system contributes significantly to the carbon footprint, in absolute figures between 1-2 and 25 g CO_2 per pkm. The contribution of the rolling stock is considerable lower, in most countries the operation phase still has the biggest impact on the carbon footprint: In countries with a carbon intense electricity mix, the share is low as 13% (Germany) or 19% (Belgium). In countries with carbon-low electricity mixes (hydro- and nuclear power), the share of the rail infrastructure is higher (Switzerland: 96 %, Norway: 98 %)

Figure 6.1: Carbon Footprint of passenger rail transport in selected countries



Source: own calculation, the values for the car has been taken from the ecoinvent database, e.g.Tuchschmid & Halder (2010). The characteristics of the car: EURO5-motor, 6.5l Diesel per 100km, loadfactor: 1.6 people.

Figure 6.2: Carbon Footprint of freight rail transport in selected countries



Source: own calculation, the values for the lorry has been taken from the ecoinvent database, the characteristics of the lorry: EURO5-engine, semi-trailer (40 ton), loadfactor: 10 tons.

The following conclusions can be drawn from this study:

- In most European countries the carbon footprint of rail infrastructure for passenger traffic is between 5 and 10g of CO_2 per pkm, in cases with a lower traffic performance (e.g. Norway) the impact is higher. In countries with a high load factor (e.g. India or Japan), the carbon footprint of the rail infrastructure is considerably lower (1-2g of CO_2)
- The carbon footprint of the rolling stock is almost neglectable, only 0.1 to 1g of CO_2 are accounted.

- The environmental advantage of the railways compared to road persists even with the inclusion of vehicle and traffic network. In the Ecoinvent database a carbon footprint of 20.7 g of CO_2 is noted for the vehicle production, maintenance and disposal, the road infrastructure of the streets lies in the same order of magnitude as the rail infrastructure (9 g CO_2 per pkm).
- Around 7g of CO_2 have to be added in Germany for the operation of the buildings (heating and cooling), around 4g of CO_2 in Spain[31]. This share is not negligible and is one of the most promising fields for a higher energy efficiency of the railways. However, as the most transport comparisons don't consider the operation of buildings, these emissions should not be included for comparisons reasons.

[31] All of the other countries did not send data about the operation of the buildings. Therefore the energy consumption of the other countries was estimated based on the German figures.

- CO_2-emissions of operation are low in countries with a high share of renewable or nuclear energy for electricity production. In these cases the impact of infrastructure has a high share on total emissions. Therefore the assumptions for estimating the impact of infrastructure are more sensitive than in countries with a higher contribution of operation.
- The infrastructure emissions for the freight transport are as well as the passenger transport country specific, but in general the same conclusions can be drawn: The higher the load factor and usage of rail, the lower the rail infrastructure.

6.2 UIC-Tools “EcoPassenger” & “EcoTransIT” and the infrastructure

Currently, the UIC-Tools “EcoPassenger” and “EcoTransIT” do not show any impact of the infrastructure. With this study, the needed methodology and values for rail transport has been developed and are available also for integration in both tools. The authors propose one of he following options:

- **Option A: Use the average values per country**
  The impact of infrastructure can be determined for each country and shown in the UIC-Tools with the methodology developed in this survey and the available statistical data sources. .
  To calculate the environmental impacts of rail infrastructure, at least the share of bridges, tunnels and normal tracks and the transport performance (Gtkm, pkm, tkm) have to be gathered for each represented country in the UIC-Tools .
  For the other transport modes (road, ship and air), corresponding infrastructure data have to be determined.
- **Option B: Use values per train type (regional / intercity / high speed trains)**
  The differentiation of the impacts into train types (e.g. the rail infrastructure for regional trains) is the adequate methodology for EcoPassenger, because the impacts of operation are also differentiated into train types.
  It can be calculated with the current methodology, but more statistical data is required: For each represented country, the following network specific details has to be gathered for **each line of the network**: length of tracks, share of electrified lines, share of bridges / tunnels / normal track, transport performance in Gtkm (all operators), transport performance in pkm (all operators), transport performance in tkm (all operators).
  For the other transport modes (road, ship and air), the infrastructure data have to be calculated more in detail (separate analysis for highways, regional streets and streets in cities).
  So far thise information is only available for the railway system in Germany.

For both options we propose the following constraints:

- Show the impact of infrastructure with an additional selector (similar to the consideration of the RFI for the air traffic).
- Show the impact of infrastructure always as separate values

- Show the impact of infrastructure always for all modes in a comparable classification (methodology, boundaries)
- Include a comprehensible documentation of the methodology used for the assessment of infrastructure into the methodology report.

7 Literature & References

7.1 Literature

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7.3 Literature Review

7.3.1 Overview

[1] **Uni Halle 2002**	Ökobilanzierung von Schienenverkehrssystemen am Bsp. des ICE-Verkehrs; von Rozycki (2003): Ecology Profile of the German High Speed Passenger Train
[2] **von Rozycki & Koese & Schwarz 2003**	Ecology Profile of the German High-speed Rail. Passenger Transport System, ICE
[3] **Spielmann & Dones & Bauer 2007**	Life Cycle Inventories of Transport Services. Final report ecoinvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.
[4] **Frischknecht&Stucki 2009**	Primärenergiefaktoren von Transportleistungen Version 1.4, 27. Juli 2009
[5] **Tuchschmid 2010**	Grundlagenbericht: Hintergrund, Methodik & Emissionsfaktoren. www.mobitool.ch
[6] **Chester 2008**	Life-cycle Environmental Inventory of Passenger Transportation in the USA. http://www.escholarship.org/uc/item/7n29n303
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[8] **Chester & Horvath 2010**	Life-cycle assessment of high-speed rail - the case of California. http://iopscience.iop.org/1748-9326/5/1/014003/media
[9] **EPD 2009**	Product Category Rules (PCR). Version 1.0
[10] **EPD 2010**	Environmental Product Declaration for the railway infrastructure on the Bothnia Line
[11] **RSSB 2010**	Whole Life Carbon Footprint of the Great Britain Rail Industry.
[12] **Tuchschmid 2009**	Carbon Footprint of High-Speed railway infrastructure (Pre-Study)
[13] **Schmied & Mottschall 2010**	Treibhausgasemissionen durch die Schieneninfrastruktur und Schienenfahrzeuge in Deutschland
[14] **SNCF & Ademe 2009**	Bilan carbone ferroviaire global: La Ligne a Grande Vitesse Rhin-Rhone au service d'une Europe durable. http://www.bilan-carbone-lgvrr.fr/documents-dinformation
[15] **Systra 2011**	High Speed Rail contribution. Carbon footprint methodology and results
[16] **Loffredo,& Fedele**	Loffredo, F., Fedele, P., Severini, M.: The climatic mark of railway infrastructural projects; in: Ingegneria Ferroviaria 3/2011

& Severini 2011	
[17] Zimmer et al. 2009	RENEWBILITY „Stoffstromanalyse nachhaltige Mobilität im Kontext erneuerbarer Energien bis 2030
[18] EPD 2011	Spactum – The Climate is Right for Trains
[19] Stripple 2001	Life Cycle Assessment of Road. A Pilot Study for Inventory Analysis
[20] Keoleian et al. 2005	Life Cycle Modelling of Concrete Bridge Design
[21] Kendall & Harvey & Lee 2009	A Critical Review of Life Cycle Assessment Practice for Infrastructure Materials
[22] Chang & Kendall 2011	Life cycle greenhouse gas assessment of infrastructure construction for California's high-speed rail system

7.3.2 Description of sources

[1]	**Uni Halle 2002**
Title	Ökobilanzierung von Schienenverkehrssystemen am Bsp. des ICE-Verkehrs
Author(s)	Uni Halle
Commissioner	Bahn-Umwelt-Zentrum
Year	2002
Language	German
Internet	-
Type	LCA
Description	Focus of the study is the compilation of an ecology profile of the ICE passenger transport system in Germany. Details see [2]
Transport Mode(s)	Passenger transport with ICE trains
System Boundaries	
Region or Line	Reference line: Hannover-Würzburg; Germany
Processes	▪ Production of traction energy ▪ Production of stationary energy ▪ Vehicle fleet (operation, construction, maintenance) ▪ Track system (operation, construction, maintenance), ▪ Railway stations (operation, construction, maintenance) ▪ Maintenance centres (operation, construction, maintenance) ▪ Feeder traffic
Reference year(s)	1999
Components	▪ Primary energy consumption (KEA) ▪ CO_2 ▪ Input of materials per service unit (MIPS)
Methodology	LCA
Data	Approximately 200 items of inventory data were collected from DB AG experts, manufacturers, site balances and the associated literature. They were allocated in order to derive 100-person-kilometre-related mass and energy consumption figures.
Results	
Sector	ICE passenger train system
Unit	Per 100 pkm
Output	▪ Infrastructure under the conditions found in Germany provides only less than 15% of the total CED per 100 pkm. ▪ Traction energy consumption clearly dominates the primary energy of the life cycle. Therefore, the rail electricity mix and more efficient traction concepts are the most promising considerations for optimizing the energy balance of the ICE transport. ▪ Tunnels and rail bridges cause high specific resource consumption. By planning new track routes, it is important to make efforts in exploring alternative track routes from the viewpoint of life cycle aspects.

[2]	von Rozycki & Koese & Schwarz 2003
Title	Ecology Profile of the German High-speed Rail. Passenger Transport System, ICE
Author(s)	von Rozycki & Koese & Schwarz
Commissioner	Martin-Luther-University, Halle-Wittenberg DB AG, Railway-Environmental-Center
Year	2003
Language	English
Internet	-
Type	LCA Case Study
Description	A screening LCA, called ecology profile, of the German high-speed passenger train system, the ICE, is presented here, based on a study conducted by the University of Halle and the Deutsche Bahn AG, the major German rail operator. In this study, the resource consumption caused by traction, manufacturing and maintenance of ICE trains, as well as construction and operation of the supporting rail infrastructure and buildings, have been evaluated using cumulative energy demand (CED), cumulative material input per service unit (MIPS) and CO_2 emissions as indicators.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	Hannover-Würzburg, Germany
Processes	▪ Production of traction energy ▪ Production of stationary energy ▪ Vehicle fleet (operation, construction, maintenance) ▪ Track system (operation, construction, maintenance), ▪ Railway stations (operation, construction, maintenance) ▪ Maintenance centres (operation, construction, maintenance) ▪ Feeder traffic
Reference year(s)	1999
Components	▪ Direct masses and end energies, cumulative energy demand (CED) ▪ Material input per service unit (MIPS; w/o water and air) ▪ CO_2 emissions
Methodology	LCA
Data	Approximately 200 items of inventory data were collected from DB AG experts, manufacturers, site balances and the associated literature. They were allocated in order to derive 100-person-kilometre-related mass and energy consumption figures.
Results	
Sector	ICE Passenger transport long distance
Unit	rtkm, tukm, tdkm, kg/100 pkm, MJ/100 pkm, kWh/100 pkm
Output	▪ Infrastructure under the conditions found in Germany provides only less than 15% of the total CED per 100 pkm. ▪ Traction energy consumption clearly dominates the primary energy of the life cycle. Therefore, the rail electricity mix and more efficient traction concepts are the most promising considerations for optimizing the energy balance of the ICE transport. ▪ Tunnels and rail bridges cause high specific resource consumption. By planning new track routes, it is important to make efforts in exploring alternative track routes from the viewpoint of life cycle aspects.

[3]	**Spielmann & Dones & Bauer 2007**
Title	Life Cycle Inventories of Transport Services
Author(s)	Spielmann & Dones & Bauer
Commissioner	Swiss Centre for Life Cycle Inventories – ecoinvent Centre
Year	2007
Language	English
Internet	-
Type	ecoinvent report No. 14, Lifecycle Analysis
Description	The report describes methodology and background data for transport services in order to update and complete a variety of product life cycles in Ecoinvent v2.0. Generic background data have been generated for four modes of transport (air-, rail-, road- and water transport) to account for environmental interventions due to the transportation between two process steps of a product system. The data represent average transport conditions in Switzerland and Europe.
Transport Mode(s)	Road, Rail, Air, Water
System Boundaries	
Region or Line	Swiss, Europe
Processes	▪ Production of traction energy ▪ Vehicle fleet (operation, construction, maintenance, disposal) ▪ Track system (operation, construction, maintenance, disposal)
Reference year(s)	Recent
Components	▪ Energy consumption and emissions (several groups)
Methodology	LCA
Data sources	Several
Results	
Sector	Goods and passenger transportation
Unit	kg/tkm, kWh/tkm, MJ/tkm, kg/pkm, kWh/pkm, MJ/pkm
Output	Description of updated methodology and database for emission factors in Ecoinvent v. 2.0

[4]	Frischknecht&Stucki 2009
Title	Primärenergiefaktoren von Transportdienstleistungen
Author(s)	Rolf Frischknecht and Matthias Stucki
Commissioner	Amt für Hochbauten der Stadt Zürich
Year	2009
Language	German
Internet	www.esu-services.ch/fileadmin/download/Transportsysteme_v2.2_2011.pdf
Type	LCA-Database for Ecoinvent
Description	Description of methodology for the determination of energy and emission factors for transport services
Transport Mode(s)	Road, Railway, Ship, Aviation
System Boundaries	
Region or Line	Switzerland, Germany (ICE), Europe (Aviation), Ocean (Seaship)
Processes	▪ Production of traction energy ▪ Vehicle fleet (operation, construction, maintenance, disposal) ▪ Track system (operation, construction, maintenance, disposal)
Reference year(s)	2005ff.
Components	▪ Primary energy ▪ CO_2 ▪ CO_2-eqivalent ▪ Environmental impact ranking points
Methodology	LCA, based on [Spielmann & Dones & Bauer 2007]
Data sources	Ecoinvent v2.01
Results	
Sector	Several categories of transport vehicles and vessels
Unit	MJ or CO2eq per pkm, tkm, vehicle-km
Output	Result tables with specific values (operation, track system, rolling stock) for each vehicle type

[5]	**Tuchschmid 2010**
Title	Mobitool
Author(s)	Matthias Tuchschmid
Commissioner	
Year	2010
Language	German, French
Internet	*www.mobitool.ch*
Type	Methodology Report, Data Sheets
Description	
Transport Mode(s)	Road, Rail, Ship, Aviation, virtual mobility
System Boundaries	
Region or Line	Switzerland
Processes	▪ Production of traction energy ▪ Vehicle fleet (operation, construction, maintenance, disposal) ▪ Track system (operation, construction, maintenance, disposal)
Reference year(s)	2005ff.
Components	▪ Primary energy ▪ CO_2 ▪ CO_2-eqivalent ▪ Other emissions
Methodology	LCA, based on Ecoinvent et.al.
Data sources	Ecoinvent v2.01
Results	
Sector	Several categories of transport vehicles and vessels
Unit	MJ or CO2eq per pkm, tkm, vehicle-km
Output	Result tables with specific values (operation, track system, rolling stock) for each vehicle type

[6]	Chester 2008
Title	Life-cycle Environmental Inventory of Passenger Transportation in the USA
Author(s)	Chester
Commissioner	Institute of Transportation Studies, UC Berkeley
Year	2008
Language	English
Internet	http://www.escholarship.org/uc/item/7n29n303
Type	Dissertation, LCA
Description	The goal of this project is to develop comprehensive life-cycle assessment (LCA) models to quantify the energy inputs and emissions from autos, buses, heavy rail, light rail and air transportation in the U.S. associated with the entire life cycle (design, raw materials extraction, manufacturing, construction, operation, maintenance, end-of-life) of the vehicles, infrastructures, and fuels involved in these systems. Energy inputs are quantified as well as greenhouse gas and criteria air pollutant outputs. Inventory results are normalized to effects per vehicle-lifetime, VMT, and PMT.
Transport Mode(s)	Automobiles, Buses, Light Rail, Heavy Rail and Air
System Boundaries	
Region or Line	USA (BART, Caltrain, Muni, Green Line, CAHSR)
Processes	▪ Production of traction energy ▪ Production of stationary energy ▪ Vehicle fleet (operation, construction, maintenance) ▪ Track system (operation, construction, maintenance), without tunnels and bridges ▪ Railway stations (operation, construction, maintenance) ▪ Maintenance centres (operation, construction, maintenance) ▪ Other buildings (parkings, construction and maintenance)
Reference year(s)	2005
Components	▪ Energy ▪ GHG (CO2, CH_4, N_2O), other emissions to air (SO_2, CO, NO_x, VOC, Pb, PM_{10})
Methodology	LCA, EIO-LCA, SimaPro
Results	
Sector	Passenger transport long distance
Unit	Functional units are impacts per vehicle lifetime, VMT and PMT
Summary	Total life-cycle-energy consumption is significantly larger than vehicle operation: ▪ Passenger cars: +39-56% ▪ Buses: +43% ▪ Rail: +39-150% ▪ Air: +24-31% Significant increase also for other components

[7]	Chester & Horvath 2009
Title	Environmental assessment of passenger transportation should include infrastructure and supply chains.
Author(s)	Chester, V.; Horvath. A
Commissioner	-
Year	2009
Language	English
Internet	http://iopscience.iop.org/1748-9326/4/2/024008
Type	Scientific report, Lifecycle Analysis
Description	Onroad, rail, and air travel are inventoried to determine energy consumption, greenhouse gas (GHG) emissions, and criteria air pollutant (CAP) emissions (excluding PM, lead, and ozone due to lack of data). An Hybrid LCA approach was used. The End-of-life phases are not included in the analysis.
Transport Mode(s)	Automobiles, Buses, Light Rail, Heavy Rail and Air
System Boundaries	
Region or Line	USA (BART, Caltrain, Muni, Green Line, CAHSR)
Processes	▪ Manufacturing, maintenance, operation, repair and insurance of rail vehicles ▪ Construction, maintenance, operation and insurance of rail infrastructure (without tunnels and bridges) ▪ Fuel Production
Reference year(s)	▪ 2005 (Automobiles)
Components	▪ Energy ▪ CO_2-equivalents ▪ Sulphur dioxide ▪ Nitrogen oxides ▪ Carbon Monoxide
Methodology	Hybrid LCA-approach (process-based and economic input-output analysis-based)
Results	
Sector	Passenger transport long distance
Unit	MJ/PKT, gCO2e/PKT and mg air pollutant/PKT
Output	Total life-cycle energy inputs and greenhouse gas emissions contribute an additional 63% for onroad, 155% for rail, and 31% for air systems over vehicle tailpipe operation. Ranges in passenger occupancy can easily change the relative performance of modes.

[8]	Chester & Horvath 2010
Title	Life-cycle assessment of high-speed rail - the case of California
Author(s)	Chester
Commissioner	-
Year	2010
Language	English
Internet	http://iopscience.iop.org/1748-9326/5/1/014003/media
Type	Scientific report, Lifecycle Analysis
Description	The considerable investment in California high-speed rail has been debated for some time and now includes the energy and environmental tradeoffs. The per-trip energy consumption, greenhouse gas emissions, and other emissions are often compared against the alternatives (automobiles, heavy rail, and aircraft), but typically only considering vehicle operation.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	California High Speed Rail (CAHSR)
Processes	▪ Production of traction energy ▪ Production of stationary energy ▪ Vehicle fleet (operation, construction, maintenance) ▪ Track system (operation, construction, maintenance), without tunnels and bridges ▪ Railway stations (operation, construction, maintenance) ▪ Maintenance centres (operation, construction, maintenance) ▪ Other buildings (parkings, construction and maintenance)
Reference year(s)	
Components	▪ Energy ▪ GHG, other emissions to air (SO_2, CO, NO_x, VOC, Pb, PM_{10})
Methodology	The methodology follows Chester and Horvath (2009), which details the LCI of automobiles, buses, commuter rail, and aircraft,
Data sources	SimaPro, Ecoinvent Database 1.3, EIO-LCA
Results	
Sector	Passenger transport long distance
Unit	MJ/pkm, g/pkm, mg/pkm
Output	Ranges of indicators dependent from load factor, average and marginal emissions, return-of-investment-emissions (energy and GHG payback)

[9]	EPD 2009
Title	Product Category Rules (PCR)
Author(s)	EPD
Commissioner	
Year	2009
Language	English
Internet	-
Type	Methodology: PCR for the assessment of environmental performance of Rail Transport and Railway Infrastructure
Description	This document describes the Product Category Rules (PCR) for the assessment of environmental performance of Rail Transport and Railway Infrastructure within the EPD (Environmental Product Declaration) framework. The PCR describes how to perform the underlying Life Cycle Assessment and other environmental assessments for the development of an EPD according to ISO 14025 and ISO 14040ff.
Transport Mode(s)	Railway
System Boundaries	▪
Region or Line	Sweden
Processes	▪ Production of traction energy ▪ Production of stationary energy ▪ Vehicle fleet (operation, construction, maintenance, disposal) ▪ Track system (operation, construction, maintenance), ▪ Railway stations (operation, construction, maintenance) ▪ Maintenance centres (operation, construction, maintenance)
Reference year(s)	The PCR document is valid for three years from 2009.
Components	CO_2 equivalents
Methodology	LCA
Data sources	Ecoinvent Database for Europe, EAA (European Aluminium Association), ICA (International Copper Association), IISI (International Iron and Steel Institute), PE Plastics Europe, EIME (Environmental Information and Management Explorer) EcoBilan, CORINAIR
Results	
Sector	Rail Transport and Railway Infrastructure
Unit	pkm, tkm, SI units, kWh for electricity, kW for power
Output	Methodology

[10]	EPD 2010
Title	Environmental Product Declaration for the railway infrastructure on the Bothnia Line
Author(s)	EPD
Commissioner	-
Year	2010
Language	English
Internet	-
Type	Environmental Product Declaration (EPD)
Description	impact of railway infrastructure on the Bothnia Line
Transport Mode(s)	Railway
System Boundaries	
Region or Line	The Swedish Bothnia Line
Processes	▪ Track system (operation, construction, maintenance),
Reference year(s)	2009
Components	▪ Materials ▪ Energy ▪ Land use ▪ Noise ▪ Risk ▪ CO_2-equivalents ▪ Other impact categories: acidification, Ozone depletion, POCP, Eutrophication ▪ Output material: for recycling, waste
Methodology	LCA according to PCR and ISO 14025
Data sources	Several
Results	
Sector	Railway infrastructure
Unit	kg, MJ, m^2 per km railway infrastructure
Output	Impacts over 60 years, without transport services

[11]	**RSSB 2010**
Title	Whole Life Carbon Footprint of the Great Britain Rail Industry
Author(s)	Best Foot Forward Ltd
Commissioner	RSSB
Year	2010
Language	English
Internet	-
Type	Inventory
Description	GHG emissions for the GB rail network, in 2008/9.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	Great Britain
Processes	▪ Traction Energy (Diesel, Electricity) ▪ Staffing (Offices, Business travel, Services) ▪ Subsystems (Track, Depot, Structures, Stations, Rolling Stock, etc.)
Reference year(s)	2008/09
Components	▪ CO_2-equivalents
Methodology	Carbon footprint: This method builds on existing recognized greenhouse gas accounting principles and, in particular, the Greenhouse Gas Protocol and the new PAS 20504 developed jointly by BSI, Defra and the Carbon Trust.
Data sources	Several
Results	
Sector	Rail industry in GB
Unit	Total CO_2e in tonnes
Output	The total results show annual emissions for the GB rail industry of 5,5 $MtCO_2$e Distribution: Traction energy 63% Staffing and services 3% Track 9% Rolling Stock 3% Stations 4% Depots 9% Structures 4% (Brigdes, Earthworks, Tunnels…) Electrification Systems 1% Train Control Systems 4%

[12]	**Tuchschmid 2009**
Title	Carbon Footprint of High-Speed railway infrastructure (Pre-Study)
Author(s)	Tuchschmid
Commissioner	The International Union of Railways (UIC)
Year	2009
Language	English
Internet	-
Type	Scientific report, Lifecycle Analysis
Description	This report describes a methodology for an ecological assessment of transport infrastructure of High-Speed railway.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	Europe
Processes	▪ Production of traction energy ▪ Vehicle fleet (operation, construction) ▪ Track system (operation, construction), ▪ Railway stations (operation, construction) ▪ Maintenance centres (operation, construction)
Reference year(s)	
Components	▪ Energy ▪ CO_2 and other emissions to air (SO_2, NO_x, VOC, PM_{10})
Methodology	LCA
Data	Ecoinvent database
Results	
Sector	High-Speed railway
Unit	g/pkm
Output	The carbon footprint of the infrastructure is mainly determined by the track system. The most important factor is the share of bridges and tunnels: The higher the part of bridges / tunnels, the higher the carbon footprint of the infrastructure.

[13]	Schmied & Mottschall 2010
Title	Treibhausgasemissionen durch die Schieneninfrastruktur und Schienenfahrzeuge in Deutschland
Author(s)	Martin Schmied, Moritz Mottschall, Öko-Institut e.V.; in cooperation with DB Umweltzentrum
Commissioner	Umweltbundesamt Dessau
Year	2010
Language	German
Internet	-
Type	Scientific report, Lifecycle Analysis
Description	The study develops a methodology to estimate greenhouse gas emissions of railway infrastructure and vehicles based on the Product Category Rules for preparing an Environmental Product Declaration (EPD) for Interurban railway transport services of passengers, Railway transport services of freight and Railways and determines all greenhouse gas emissions of the railway transport in Germany. The reference year is 2008. The study uses a bottom up approach and thereby gains detailed results for every track section.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	Germany
Processes	▪ Operation ▪ Vehicle fleet: Construction and maintenance of vehicles ▪ Construction, maintenance and operation of railway infrastructure ▪ Delivery of energy for all processes
Reference year(s)	2008
Components	▪ CO_2 & CO_2-equivalents
Methodology	LCA
Data sources	DB AG, Bundesnetzagentur, VDV, several studies, Ecoinvent database, Gemis 4.5, TREMOD 4.17
Results	
Sector	Passenger transport regional and long distance, freight transport.
Unit	g/pkm, g/tkm
Output	The study is currently unpublished.

[14]	SNCF & Ademe 2009
Title	1er Bilan Carbone ferroviaire global – La ligne a Grande Vitesse Rhin-Rhône au service d'une Europe durable
Author(s)	Ademe, RFF, SNCF
Commissioner	
Year	2009
Language	French
Internet	http://www.bilan-carbone-lgvrr.fr/
Type	Summary of Results, Lifecycle Analysis
Description	Evaluation of CO_2 emissions for the construction of new LGV lines Rhine-Rhone. Estimation of saved CO_2-emissions by changing traffic from road and air to the new lines
Transport Mode(s)	Railway
System Boundaries	
Region or Line	High speed lines Rhine-Rhone
Processes	▪ Vehicle fleet (construction, maintenance) ▪ Track system (construction, maintenance) ▪ Railway stations and other buildings (construction, operation, maintenance)
Reference year(s)	
Components	▪ CO_2-equivalents
Methodology	LCA
Data sources	several
Results	
Sector	Passenger transport long distance
Unit	g/pkm?
Output	Total CO_2-emissions of construction and maintenance over 30 years; Saved CO2-emissions by changing modal split from road and air to rail until 2040

[15]	Systra 2011
Title	High Speed Rail contribution. Carbon footprint methodology and results
Author(s)	Systra, Matthias Tuchschmid
Commissioner	The International Union of Railways (UIC)
Year	2011
Language	English
Internet	-
Type	LCA
Description	The study aims to investigate the global warming impact of High Speed Rail through a detailed study of the carbon footprint of four high speed line projects in France and Asia and a simplified modal comparison with road and air transport.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	High Speed Lines over the world
Processes	▪ Production of traction energy ▪ Vehicle fleet (operation, construction) ▪ Track system (operation, construction), ▪ Railway stations (operation, construction) ▪ Maintenance centers (operation, construction)
Reference year(s)	2004
Components	CO_2-equivalents
Methodology	LCA
Data	Data collection from Systra's archives, but also on investigation in research literature on the subject. The Ecoinvent database has been chosen to provide emission factors.
Results	
Sector	Passenger transport long distance
Unit	Emissions/pkm
Output	CO_2 –emissions for the following Lines: LGV Med in France: Valence - Marseille LGV SEA in France: Tours - Bordeaux HSR in Taiwan: Taipeh – Kaohsiung HSR in China: Bejing – Tianjin

[16]	**Loffredo,& Fedele & Severini 2011**
Title	The climatic mark of railway infrastructural projects
Author(s)	Loffredo, F., Fedele, P., Severini, M.
Commissioner	Italferr
Year	2011
Language	Italian, English
Internet	-
Type	Describtion of Methodology
Description	Description of a methodology for the determination of the carbon footprint of railway infrastructural projects, based on ISO 14064.1:2006.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	Bari S. Andrea-Biletto (application case)
Processes	▪ Development of the project ▪ Use of building material and precasts ▪ transport of materials ▪ Processing, installation and building ▪ Clearings and avoided emissions
Reference year(s)	-
Components	▪ CO_2 emissions
Methodology	LCA, based on ISO 14064.1:2006
Data	
Results	
Sector	Railway Infrastructure
Unit	Tonnes CO_2
Output	Case Study: More than 80% of CO2-emissions originates from the production of building materiel, 13% from operational activities performed at the building site and 5% from transport of materials

[17]	**Zimmer et al. 2009**
Title	RENEWBILITY „Stoffstromanalyse nachhaltige Mobilität im Kontext erneuerbarer Energien bis 2030“
Author(s)	Zimmer, W.; Fritsche, U.; Hacker, F.; Hochfeld, C.; Jenseit, W.; Schmied, M.; in cooperation with: DLR-Institut für Verkehrsforschung (Berlin); scientific partners: ifeu – Institut für Energie- und Umweltforschung (Heidelberg); DBFZ Deutsches Biomasse-Forschungsinstitut; Professur für Verkehrsströmungslehre der Technischen Universität Dresden
Commissioner	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)
Year	2009
Language	German
Internet	http://www.oeko.de/oekodoc/1016/2009-121-de.zip
Type	Scientific report
Description	In the research project "renewability - Material Flow Analysis for Sustainable Mobility in the Context of Renewable Energy until 2030" a methodically consistent and transparent modelling tool within the scope of the project to identify sustainable mobility options was developed for Germany. Different measures with a focus on climate change protection were considered in scenario analyses up to the year 2030. Both their environmental and socio-economic impact were assessed in order to deduce political recommendations for their implementation. The analysis of material flows concentrated on process chains which trace the lifecycle from demand via manufacturing and distribution needs to the extraction of resources.
Transport Mode(s)	Passenger cars, light and heavy duty vehicles, buses, rolling stock, inland vessels, aircraft
System Boundaries	
Region or Line	Germany
Processes	Vehicle operation (including electricity production) Vehicle production (Rolling Stock)
Reference year(s)	▪ 2005 - 2030
Components	Material use (vehicle production) Energy use (vehicle use and production) CO_2-equivalents (vehicle use and production) Costs (vehicle use and production)
Methodology	Literature review, expert consultation
Data	EcoInvent Database (Air, Rail, inland vessel), TREMOD, literature review
Results	
Sector	Passenger and freight transport
Unit	t $CO2_e$/a, PJ/a, vkm/a,
Output	Greenhouse gas emissions of passenger transport and freight transport in 2005, 2010, 2020 and 2030 in different scenarios.

[18]	**EPD 2011**
Title	Spactum – The Climate is Right for Trains
Author(s)	Bombardier Transportation
Commissioner	-
Year	2011
Language	English
Internet	http://www.bombardier.com/files/en/supporting_docs/SPACIUM_EPD.pdf
Type	Environmental Product Declaration (EPD)
Description	LCA of railway vehicle based on ISO 14025:2006 and Product category Rules for Rail vehicles (PCR 2009:05, version 1.1).
Transport Mode(s)	Railway
System Boundaries	
Vehicle	SNCF Francilien commuter train, built on the BOMBARDIER SPACIUM platform.
Region	France
Processes	▪ Construction, maintenance and operation of railway vehicle
Reference year(s)	-
Components	▪ Materials ▪ Energy ▪ Noise ▪ Waste ▪ CO_2-equivalents ▪ Other impact categories: acidification, Ozone depletion, POCP, Eutrophication
Methodology	LCA, based on ISO 14025:2006
Data	
Results	
Sector	Railway vehicles
Unit	kg/100 pkm; MJ/100 pkm
Output	Impact per 100 passenger km in a lifetime of 40 Years with 200,000 vkm per year.

[19]	Stripple 2001
Title	Life Cycle Assessment of Road. A Pilot Study for Inventory Analysis.
Author(s)	Håkan Stripple
Commissioner	IVL Swedish Environmental Research Institute Ltd
Year	2001
Language	English
Internet	http://www.ivl.se/download/18.7df4c4e812d2da6a416800071481/B1210E.pdf
Type	Scientific report, Lifecycle Analysis
Description	This work is a preliminary study where the road system has been studied in terms of life cycle assessment methodology.
Transport Mode(s)	Road
System Boundaries	
Region or Line	Sweden
Processes	▪ Road Construction ▪ Road Maintenance ▪ Road Operation.
Reference year(s)	▪ 1995
Components	▪ Energy use ▪ Emissions to air (CO2, CO, NOx, SO2, N2O, CH4, HC, PM, NMVOC) (Zahlen runterstellen?)
Methodology	LCA
Results	
Sector	Road System
Unit	MJ/km, MJ/m^2, g/km, g/m^2
Output	The situation for a complete road system is very complex and the analysis in this study covers only one simplified case, namely the situation described by the input variables in this model.

[20]	Keoleian et al. 2005
Title	Life Cycle Modelling of Concrete Bridge Design
Author(s)	Gregory A. Keoleian, Alissa Kendall, Jonathan E. Dettling, Vanessa M. Smith, Richard F. Chandler, Michael D. Lepech and Victor C. Li
Commissioner	-
Year	2005
Language	English
Internet	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.146.2681&rep=rep1&type=pdf
Type	Scientific report, Lifecycle Analysis
Description	LCA of two bridge deck systems over a 60 year service life: one using conventional steel expansion joints and the other based on a link slab design using a concrete alternative engineered cementitious composites (ECC).
Transport Mode(s)	Infrastructure
System Boundaries	
Region or Line	USA
Processes	▪ Construction of Bridges.
Reference year(s)	▪ 2003
Components	▪ GHG-Emissions in CO2equivalents by life cycle phase ▪ Air emissions (NOx, CO, PM, NMVOC, CH4 and SO2) by life cycle stage ▪ Water pollution discharges by life cycle stage
Methodology	LCA
Results	
Sector	Infrastructure
Unit	metric tonnes/life cycle, kg/life cycle
Output	Results indicate that the ECC bridge deck system has significant advantages in environmental performance: 40% less life cycle energy consumption, 50% less solid waste generation and 38% less raw material consumption. Construction related traffic congestion is the greatest contributor to most life cycle impact categories.

[21]	**Kendall & Harvey & Lee 2009**
Title	A Critical Review of Life Cycle Assessment Practice for Infrastructure Materials
Author(s)	Alissa Kendall, John Harvey and In-Sung Lee
Commissioner	-
Year	2009
Language	English
Internet	http://www.hucc.hokudai.ac.jp/~m16120/workshop2009/papers/DrKendall.pdf
Type	Scientific paper
Description	This paper reviews LCA studies of pavement systems to identify key sources of errors and uncertainties in LCA applied to long-lived infrastructure, and offers recommendations for reducing or quantifying uncertainties and errors.
Transport Mode(s)	Road
System Boundaries	
Region or Line	Comparison of different LCA studies
Processes	▪ Construction of road infrastructure (Asphalt pavement, concrete pavement)
Reference year(s)	▪ 2001-2008
Components	▪ GHG-Emissions in CO2equivalents
Methodology	LCA
Results	
Sector	Highway and Road Infrastructure
Unit	CO2e Emissions per tonne (of Bitumen or Cement)
Output	Results of this review show great variability across studies, both in their implementation and in their findings. Problems that arise in each stage of an LCA are reviewed.

[22]	Chang & Kendall 2011
Title	Life cycle greenhouse gas assessment of infrastructure construction for California's high-speed rail system
Author(s)	Brenda Changa and Alissa Kendall
Commissioner	-
Year	2011
Language	English
Internet	http://www.sciencedirect.com/science/article/pii/S1361920911000484
Type	Scientific report, Carbon Footprint
Description	Life cycle GHG emissions from construction of a proposed high-speed rail system.
Transport Mode(s)	Railway
System Boundaries	
Region or Line	USA (San Francisco to Anaheim)
Processes	▪ Construction of rail infrastructure including tunnelling and aerial structures.
Reference year(s)	▪ - einrücken
Components	▪ GHG-Emissions in CO2equivalents
Methodology	LCA
Results	
Sector	High Speed rail infrastructure
Unit	t $CO2_e$/km
Output	Construction of a high-speed rail link will emit approximately 3200 t $CO2_e$ per km. The climate change effect of construction will be offset after 6 years of operation. Construction material production contributes 80% of GHG emissions. Tunnels and aerial structures are 15% of the network but contribute 60% of emissions.

8 Annex

8.1 Further Data sources

The following project sheets delivered useful additional information about material use for the construction of railway infrastructure:

Project 1: Austria: ÖBB (2009): Umbau Arlbergeisenbahntunnel

Project 2: Belgian: Boxheimer & Mignon (2009): Liefkenshoek Railway Tunnel in Antwerpen

Project 3: France & Italy: LTF (2001): THE SAINT-MARTIN-LA-PORTE ACCESS TUNNEL

Project 4: France: RFF (2008): Contournement de Nîmes et Montpellier

Project 5: France: RFF (2008): Rhine-Rhone high-speed line

Project 6: Germany: DB (2007): Neubaustrecke Ebensfeld-Erfurt. Eisenbahnüberführung Fuellbach-talbrücke Coburg-Süd

Project 7: Germany: Krebs und Kiefer (1997): Neuer Mainzer Tunnel (Fernbahntunnel)

Project 8: Great Britain: INGENIA ISSUE (2007): High Speed 1. The UKs First High Speed Railway

Project 9: Italy: CHRYSO (2003): TGV Bologna-Milan

Project 10: Italy: CHRYSO (2004): TGV Milan-Naples

Project 11: Italy: RFI & TAV (2005): The new high speed TURIN - MILAN line

Project 12: Spain: ADIF Tunel Guadarrama

Project 13: Spain: ADIF Tuneles de Montblanc

Project 14: Sweden: EPD (2010): Environmental Product Declaration for railway bridges on the Bothnia Line

8.2 Questionnaire

In order to get as accurate answers as possible, a questionnaire has been sent mid of March 211 to the contact persons of the following railway: Belgium, France, Germany, Italy, Japan, Korea, Spain, Sweden, Switzerland and Great Britain.

Figure 8.1: Overview of the Questionnaire

Questionnaire "Infrastructure of Railways"

For the Project 'Carbon Footprint of Railways' we kindly ask you for additional data about the network in Germany.
The aim of the project is to evaluate the share of railway infrastructure of the overall carbon footprint of rail operation. It is necessary to have a clearer view on this, as the environmental advantage is sometimes questioned due to a high carbon footprint, when constructing and maintaining railway infrastructure.
Available data from UIC-statistics are filled in already, but some technical data still lacks. The preferred reference year is 2008, if available. Otherwise data from others years are welcome, too.

The first three sheets Q1-Q3 are about basic data of the network, especially the yellow fields are important. With this information, a basic Carbon Footprint of your network can be calculated (with interpolated data from other countries).

We really welcome, if you are able to fill in some further information in the Extrasheets (named EQ1- EQ7). You may help us to extend the accuracy of the whole project.

Q1: Performance data on the network of infrastructure manager DB AG in Germany
Q2: Share of bridges, tunnels and viaducts on the network of infrastructure manager DB AG in Germany
Q3: Performance data on the network of Operator DB AG in Germany (including Energyconsumption & Energymix)

EQ1: How many railway stations are in Germany?
EQ2: What's the rolling stock of the Operator 'DB AG' in Germany?
EQ3: What is the energy consumption for the railway stations / maintenance centers in Germany?
EQ4: How are the bridges constructed in Germany?
EQ5: How are the tunnels constructed in Germany?
EQ6: What kind of track bed is used in Germany?
EQ7: What kind of rail is used in Germany?

We thank you very much for your effort!

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In total 6 questionnaires has been sent back, the information is now used for the calculation of the country specific factsheets. Please note that the share of bridges and tunnels is the most important figure for determining the impact of the rail infrastructure.

Figure 8.2: Questionnaire for the determination of bridges & tunnels

What is the share of bridges / tunnels / normals tracks in Germany?

Please specify the share of tracks, bridges and tunnels at your network in Germany. Note that only the country / region of Germany is considered, not the whole area network of operation from DB AG.

normal track

bridge (all types)

tunnels (all types)

I have detailed data about the network on single / double tracks: no

I have detailed data about the share of bridges on highspeed network: no

	total [%]	Grand total [km]
normal track	96.9%	32792.3
Bridges	1.8%	611.1
Tunnels	1.3%	452
	100%	*33855*

Notes: Please note the share of normal track, bridges and tunnels.

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