EcoTransIT:
Ecological Transport Information Tool

Environmental Methodology and Data

Update 2008

Commissioned by
Railion Deutschland (Germany),
Green Cargo AB (Sweden),
Schweizerische Bundesbahnen (Switzerland),
Société Nationale des Chemins de Fer Francais (France),
Société Nationale des Chemins de Fer Belges (Belgium)
Trenitalia S.p.A (Italy)
Red Nacional de los Ferrocarriles Españoles (Spain)
English, Welsh & Scottish Railway (United Kingdom)

Heidelberg, July 2008
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1 Introduction

The first version of EcoTransIT was released in May 2003. In 2005 new data related to energy consumption and emissions factors of freight transport and energy production were entered. With the joining of three new partners in the EcoTransIT-project the data base has to be expanded. In addition the tool gets new features in an expert mode. The main changes are the following:

- Euro 4 and Euro 5 Vehicles are now registered in EcoTransIT, the emissions factors are assumed on the basis of the legal limit values.
- The emissions factors for the electricity generation in all countries are newly estimated on basis of Ecoinvent data/Ecoinvent°2006/ and have been recalculated as a result of newer statistics and new data available. So the electricity production mix of the rail companies was provided by the Railenergy project of the UIC /UIC°2007/. For most of the countries the emission factors for electricity production are now lower than before.
- Allowance of TEU as user input for transported freight.
- Variation of load factors and empty trips in the expert mode.
- Possibility to add intermodal transfers

Heidelberg, June, 2008
2 Background and task

Goods traffic causes energy consumption, carbon dioxide emissions and exhaust emissions. Progressive transport planners wish to know the eco-impact of diverse transports according to transport mode in order to reduce this impact. For this purpose Railion Deutschland (Germany),
Green Cargo AB (Sweden),
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support the internet tool EcoTransIT (Ecological Transport Information Tool). It was published for the first time in 2003.

EcoTransIT is a tool to compare the emissions and energy consumption of different transport modes for freight traffic. The transport modes to be assessed are
- road transport,
- rail transport,
- inland waterway transport,
- sea transport and
- air transport.

The user is provided with information on any individual route and variable transport volume. Thus the relevant environment related parameters of each transport process, like route characteristics and length, load factor, vehicle size and engine type, are individually taken into account. The evaluation includes energy consumption, carbon dioxide emissions and exhaust emissions.

The internet version of EcoTransIT as well as the integrated route planner have been realised by IVE/RmCon Hannover.

The basic methodology for environment calculations was developed by IFEU in cooperation with the participating railway companies. Data and methodology have been discussed and harmonised with the Swedish organisation NTM (Nätverket för Transporter och Miljön) and the NTM software NTMCALC/NTM 2003/. The methodology and data basis for ferry transport have been directly taken from NTM.

The following report summarizes the methodology and data (updated in 2008) used for the EcoTransIT online computer program. The main task is to deliver specific energy and emission data for European cargo transports.
3 System boundaries and basic definitions

3.1 Environmental impacts

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

1. Resource consumption
2. Land use
3. Greenhouse effect
4. Depletion of the ozone layer
5. Acidification
6. Eutrophication
7. Eco-toxicity (toxic effects on ecosystems)
8. Human toxicity (toxic effects on humans)
9. Summer smog
10. Noise

The transportation of cargo has impacts within all these categories. However, only for some of these categories is it possible to make a comparison of individual transports on a quantitative basis. In this version of EcoTransIT therefore the selection of environmental performance values had to be limited to a few but important parameters. The selection was done according to the following criteria:

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

The following parameters for environmental impacts of transports were selected:
Table 1  Environmental impacts included in EcoTransIT

<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Description</th>
<th>Reasons for inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEC</td>
<td>Primary energy consumption</td>
<td>Main indicator for resource consumption</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide emissions</td>
<td>Main indicator for greenhouse effect</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrogen oxide emissions</td>
<td>Acidification, eutrophication, eco-toxicity, human toxicity, summer smog</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulphur dioxide emissions</td>
<td>Acidification, eco-toxicity, human toxicity</td>
</tr>
<tr>
<td>NMHC</td>
<td>Non-methane hydro carbons</td>
<td>Human toxicity, summer smog</td>
</tr>
<tr>
<td>Particles</td>
<td>Exhaust particulate matter from vehicles (mainly diesel combustion), composition: all particle sizes, about 80% PM 2.5, 90% PM 10 (by mass)</td>
<td>Human toxicity, summer smog</td>
</tr>
<tr>
<td>Dust</td>
<td>Total exhaust Particles from vehicles and from energy production and provision (mainly power plants, refineries, sea transport of primary energy carriers), composition: all particle sizes, about 80% PM 2.5, 90% PM 10 (by mass)</td>
<td>Human toxicity, summer smog</td>
</tr>
</tbody>
</table>

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

Furthermore the greenhouse gases methane and nitrous oxide are also not included in the current version. This is due to the fact that CO₂ is the dominant greenhouse gas in the transport sector and methane emissions are therefore only of minor importance. PM emissions are defined as exhaust emissions from combustion, therefore PM emissions from abrasion and twirling are not included so far.

Location of emission sources

Depending on the impact category, the location of the emission source can be highly significant. With regard to those emissions which contribute to the greenhouse effect, the location for land bound transport modes is not relevant, whereas flights in high distances have additional climatic impacts. Regarding eco-toxicity and human toxicity on the other hand, the location of the emission source is highly relevant:

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

Therefore in EcoTransIT the results are presented as “particulates resulting from diesel...
combustion by vehicle engines” (particles) and the sum of “direct particulates and particulates resulting from extraction, conversion, transport and combustion” (dust).

System boundaries

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

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

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

Figure 1 System boundaries
3.2 Spatial differentiation

In this version of EcoTransIT, transports within and between the following countries will be considered:

Table 2 Included countries

<table>
<thead>
<tr>
<th>Austria</th>
<th>Belgium</th>
<th>Czech Republic</th>
<th>Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>France</td>
<td>Germany</td>
<td>Hungary</td>
</tr>
<tr>
<td>Italy</td>
<td>Luxembourg</td>
<td>Netherlands</td>
<td>Norway</td>
</tr>
<tr>
<td>Poland</td>
<td>Portugal</td>
<td>Slovakia</td>
<td>Slovenia</td>
</tr>
<tr>
<td>Spain</td>
<td>Sweden</td>
<td>Switzerland</td>
<td>United Kingdom</td>
</tr>
</tbody>
</table>

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

Less pronounced are the differences in end energy consumption of similar vehicles in different countries. Thus in all countries usually relatively modern trucks of different international manufacturers are used for long-distance traffic on road. For ship and air transport, the existing vehicles are likewise used internationally.

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

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

**Country specific values**: railways mix of electricity production and the route characteristic (gradient). For some countries, rail specific emission data are available, e.g. emission factors for diesel traction and the sulphur content of diesel fuel.

**Common data**: emission factors for the operation of lorry, ship and air planes, specific energy consumption for all modes.
3.3 Transport modes and propulsion systems

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

Table 3  Transport modes, vehicles and propulsion systems

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Vehicles</th>
<th>Propulsion energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>Road transport with single trucks and truck trailers/articulated trucks</td>
<td>Diesel fuel</td>
</tr>
<tr>
<td>Rail</td>
<td>Rail transport with short, average and long trains</td>
<td>Electricity and diesel fuel</td>
</tr>
<tr>
<td>Sea</td>
<td>Ocean-going sea ships and ferries</td>
<td>Heavy fuel oil / marine diesel oil</td>
</tr>
<tr>
<td>Inland waterways</td>
<td>Inland ships</td>
<td>Diesel fuel</td>
</tr>
<tr>
<td>Aircraft transport</td>
<td>Air planes</td>
<td>Kerosene</td>
</tr>
</tbody>
</table>

3.4 Elements of transport processes and routing

EcoTransIT calculates the route between the place of origin and the destination for each selected traffic type (e.g. road, rail, inland ship etc.). Depending on the traffic type EcoTransIT calculates the shortest or the fastest way. Therefore EcoTransIT differs some traffic types into different route classes, e.g. highway and local street with lorries. If there is a highway between the origin and the destination the lorry will use it probably on its route. Technically spoken a highway has a much lower resistance (factor 1,0) than a local street (factor 5,0). Thus a route on a highway has to be more than five times as long as a local street before the local street will be preferred.

The same method is used for railways and ferries. E.g. railway routing with a electrified train would also use a non-electrified track if needed (no electrified way is available) or is much shorter. A non-electrified track will be calculated with a resistance factor of 4.0 against an electrified track. This helps to find a route even if there is no electrified track available or to circumnavigate possible errors concerning the electrification of the railway net. Ferries are equipped with a user defined resistance (preferred, normal, and obstruct). The resistance factors are 1,0 for preferred, 5,0 for normal, and 10,0 for obstruct ferry routing.

The routing takes place on different traffic type networks, which are streets, railway tracks, inland waterways and sea ship routes. Depending on the selected traffic types, EcoTransIT routes on the respective traffic type network. All networks are connected with so called transit edges. These transit edges enable the routing algorithm to change a network if this is needed. This happens e.g. if the user wants to route a train run but selects city names as origin and destination and not stations. If this happens EcoTransIT has to determine the closest station to the origin and destination. These routes use the street network. The main routing between the two determined stations uses the railway network.
When using airports for origin and destination there is just one edge in-between. The length between two airports is the geographical length (spherical length) multiplied with a factor of 1.1 for start-, landing- and traffic reasons.

EcoTransIT does always take the geographical nearest station, harbour or airport from the origin / destination. This can sometimes create not realistic routes and so it is recommend selecting a station as origin/destination if the user wants to calculate a railway track.

It is also possible to select a Sidetrack or Harbour as available at the origin or destination. In this case EcoTransIT again routes on the street network to next entry point but calculates the part on the street network as the selected traffic type. This is helpful if there e.g. the station or harbour is not within the data.

3.5 Cargo specifications

Every transport vessel has a maximum load capacity which is defined by the maximum load weight allowed and the maximum volume available. Typical goods where the load weight is the restricting factor are coal, ore, oil and some chemical products. Typical products with volume as the limiting factor are vehicle parts, clothes and furniture. It is
evident that volume restricted goods need more transport vessels and in consequence e.g. more wagons for rail transport or more lorries for road transport. Therefore more vehicle weight per ton of cargo has to be transported and more energy will be consumed.

In the standard mode of EcotransIT three types of cargo are defined:

- bulk goods (coal, ore, oil, fertilizer etc.)
- the “average good”: this stands for the statistically determined average value for all transports of a given carrier in a reference year.
- volume goods (industrial parts, shopping goods such as furniture, clothes, etc.)

The cargo specification will be defined due to the typical load factor including all empty trips. For rail transport the parameter for the load factor is the relation net ton / gross ton hauled. For lorry and ship the load factor is defined as the relation net ton / max. ton capacity. The following table shows some typical load factors for different types of cargo.

### Table 4 Load factors for different types of cargo

<table>
<thead>
<tr>
<th>Type of cargo</th>
<th>Rail [net-tons/gross-tons]</th>
<th>Road [net tons / tons-capacity]</th>
</tr>
</thead>
<tbody>
<tr>
<td>hard coal, ore, oil</td>
<td>0.7</td>
<td>100%</td>
</tr>
<tr>
<td>Waste</td>
<td>0.6-0.65</td>
<td>100%</td>
</tr>
<tr>
<td>passenger cars</td>
<td>0.35</td>
<td>30%</td>
</tr>
<tr>
<td>Vehicle parts</td>
<td>0.3-0.55</td>
<td>25-80%</td>
</tr>
<tr>
<td>bananas</td>
<td>0.63</td>
<td>100%</td>
</tr>
<tr>
<td>seat furnitures</td>
<td>0.46</td>
<td>50%</td>
</tr>
<tr>
<td>Clothes</td>
<td>0.24</td>
<td>20%</td>
</tr>
</tbody>
</table>

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

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

**Bulk (heavy):** For bulk goods, at least with regard to the actual transport, a full load (in terms of weight) can be assumed. What is more difficult is assessing the lengths of the additionally required empty trips. The transport of many types of goods, e.g. coal and ore, necessitate the return transport of empty wagons. The transport of other types of goods however allows the loading of other cargo on the return trip. The possibility of taking on new cargo also depends on the type of carrier. Thus for example an inland navigation vessel is better suited than a train to take on other goods on the return trip after a shipment of coal. In general however it can be assumed that the transport of
bulk goods necessitates more empty trips than that of volume goods.

**Volume (light):** For volume goods, the capacity utilisation with regard to the actual transport trip varies a lot. Due to the diversity of goods, a typical value cannot be determined. Therefore some value must be defined to represent the transport of volume goods. The same goes for the share of additional empty trips. Here it can be assumed that volume goods necessitate fewer empty trips than bulk goods.

The share of additional empty trips depends not only on the cargo specification but also to a large extent on the logistical organisation, the specific characteristics of the carriers and their flexibility. An evaluation and quantification of the technical and logistic characteristics of the transport carriers is not possible. We use the statistical averages for the “average cargo” and estimate an average load factor and the share of empty vehicle-km for bulk and volume goods in rail, road and waterway traffic.

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

No data for the empty vehicle-km in rail transport is available. According to /Kessel und Partner 1998/ the German Railways (DB AG) share of additional empty vehicle-km was 44% in 1996. This can be explained by a high share of bulk commodities in railway transport and a relatively high share of specialised rail cars. IFEU calculations have been carried out for a specific train configuration, based on the assumption of an average load factor of 0.5 net-tons per gross ton. It can be concluded that the share of empty vehicle-km in long distance transport is still significantly higher for rail compared to road transport.

The additional empty vehicle-km for railways can be partly attributed to characteristics of the transported goods. Therefore we presume smaller differences for bulk goods and volume goods and make the following assumptions:

- The full load is achieved for the loaded vehicle-km with bulk goods. Additional empty vehicle-km are estimated in the range of 60% for road and 80% for rail transport.
- The weight related load factor for the loaded vehicle-km with volume goods is estimated in the range of 30% for all transport carriers. 20% and 10% empty vehicle-km are estimated for rail and road transport respectively.

These assumptions take into account the higher flexibility of road transport as well as the general suitability of the carrier for other goods on the return transport. The assumptions are summarised in Table 5.
### Table 5  Load factors for different types of cargo

<table>
<thead>
<tr>
<th>Rail</th>
<th>Load factor train without empty trips [net-tons/gross-tons]</th>
<th>Additional empty trips</th>
<th>Load factor rail including empty trips [net-tons/gross-tons]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk (heavy) cargo*</td>
<td>0.72</td>
<td>+80%</td>
<td>0.6</td>
</tr>
<tr>
<td>Average cargo</td>
<td>n.a.</td>
<td>n.a.</td>
<td>0.5</td>
</tr>
<tr>
<td>Volume (light) cargo*</td>
<td>0.44</td>
<td>+20%</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Road</th>
<th>Load factor lorry without empty trips [net-tons/capacity]</th>
<th>Additional empty trips</th>
<th>Load factor lorry including empty trips [net-tons/capacity]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk (heavy) cargo*</td>
<td>100%</td>
<td>+60%</td>
<td>63%</td>
</tr>
<tr>
<td>Average cargo</td>
<td>58%</td>
<td>+17%</td>
<td>50%</td>
</tr>
<tr>
<td>Volume (light) cargo*</td>
<td>30%</td>
<td>+10%</td>
<td>27%</td>
</tr>
</tbody>
</table>

* Estimated values; n.a.: not available
Source: KBA, different railway companies, IFEU estimation

Due to a lack of data, the load factor for inland waterways is estimated as 70%/50%/30% (bulk/average/volume, including empty trips).
4 Energy and emission data

4.1 Energy supply

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

Energy chain of electricity production:

- Exploration and extraction of the primary energy carrier (coal, oil, gas, nuclear etc.) and transport to the entrance of the power plant
- Conversion within the power plant (including construction and deposal of power stations)
- Energy distribution (transforming and cable losses)

Energy chain of fuel production:

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

Figure 2 Energy chain for diesel fuel and electricity

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

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

Figure 3  Energy chain for fuel and electricity

![Energy chain for fuel and electricity](image)

4.1.1 Exploration, extraction, transport and production of diesel fuel

The emission factors and energy demand for the construction and disposal of refineries, exploration and preparation of different input fuels; the transport to the refineries; the conversion in the refinery and transport to the filling station are taken from /Ecoinvent 2006/. The following table shows the specific figures for the emissions and the energy consumption for the prechain.

Table 6  Emission factors and energy consumption for energy production of fuels

<table>
<thead>
<tr>
<th></th>
<th>Efficiency*</th>
<th>CO2</th>
<th>NOx</th>
<th>SO2</th>
<th>NMVOC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg</td>
<td>g</td>
<td>g</td>
<td>G</td>
<td>g</td>
</tr>
<tr>
<td>Gasoline</td>
<td>75%</td>
<td>0.67</td>
<td>2.2</td>
<td>6.2</td>
<td>2.1</td>
<td>0.30</td>
</tr>
<tr>
<td>Diesel</td>
<td>79%</td>
<td>0.47</td>
<td>1.8</td>
<td>4.4</td>
<td>1.5</td>
<td>0.24</td>
</tr>
<tr>
<td>Kerosene</td>
<td>79%</td>
<td>0.45</td>
<td>1.8</td>
<td>4.3</td>
<td>1.5</td>
<td>0.23</td>
</tr>
<tr>
<td>Marine Diesel Oil</td>
<td>79%</td>
<td>0.40</td>
<td>1.7</td>
<td>4.0</td>
<td>1.5</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Efficiency: Relation final energy/primary energy; emission factors related to final energy (kg fuel)

Source: Ecoinvent 2006
4.1.2 Electricity production

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

- Each country in Europe has its own electricity production mix; in some countries the railways have, at least partially, their own power plants or buy a special mix of electricity.
- The split of production differs between night and day and also between winter and summer. For example gas-fired power plants can more easily accommodate changes in the power demand than coal fired power plants. This means that during the night the percentage of electricity that is generated by coal is higher than during the day. The emissions of a coal-fired plant are usually higher than those of a gas fired plant.
- The liberalisation of the energy market leads to an international trade of electricity making the determination of a specific electricity mix even more difficult.
- For combined production of heat and power (CHP) the total efficiency of the energy production is higher. For the allocation of the environmental impacts of CHP different methodologies are proposed. (described e. g. in /Ecoinvent 2003/). We use the allocation based on the energy content of electricity and heat. This allocation methodology does not take into account the different exergy contents of the two products heat and power into estimation. So electricity and heat are treated like equivalent products. Compared with other allocation methodologies (e. g. exergy content), due to energy content allocation, the electricity production gets a relatively high benefit. The efficiency of CHP-power plants is assessed with 80% for all countries /Ecoinvent 2003/.

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

The values for the Energy mix of the electricity production are taken from Railenergy /UIC 2007/ and. If no values are available data from EU-statistics /Eurostat 2007a/ and other sources (see table next page) are used. The data for CHP are taken from /Eurelectric 2005/ (share of electricity generation in CHP produced thermal on conventional thermal electricity production). The following table shows the values used.
### Table 7  Energy split of electricity consumption used by railways 2005*

<table>
<thead>
<tr>
<th>Country</th>
<th>Source</th>
<th>Solid fuels</th>
<th>Oil</th>
<th>Gas</th>
<th>Nuclear</th>
<th>Renewables</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>ÖBB 2006</td>
<td>6.4%</td>
<td>1%</td>
<td>8.3%</td>
<td>0.0%</td>
<td>84.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>BE</td>
<td>UIC 2007</td>
<td>11.8%</td>
<td>1.9%</td>
<td>25.3%</td>
<td>58.1%</td>
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<td>0.0%</td>
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</tr>
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<td>41.6%</td>
<td>3.5%</td>
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</tr>
<tr>
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<td>UIC 2007</td>
<td>53.4%</td>
<td>0.1%</td>
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<td>26.7%</td>
<td>10.9%</td>
<td>0.6%</td>
</tr>
<tr>
<td>DK</td>
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<td>52.3%</td>
<td>2.1%</td>
<td>19.0%</td>
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<td>26.5%</td>
<td>0.1%</td>
</tr>
<tr>
<td>ES</td>
<td>UIC 2007</td>
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<td>3.8%</td>
<td>18.3%</td>
<td>21.5%</td>
<td>18.5%</td>
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</tr>
<tr>
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<td>UIC 2007</td>
<td>19.0%</td>
<td>0.0%</td>
<td>54.0%</td>
<td>19.0%</td>
<td>8.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>FR</td>
<td>UIC 2007</td>
<td>4.1%</td>
<td>1.8%</td>
<td>3.2%</td>
<td>85.8%</td>
<td>4.7%</td>
<td>0.4%</td>
</tr>
<tr>
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<td>UIC 2007</td>
<td>19.5%</td>
<td>1.3%</td>
<td>34.5%</td>
<td>38.7%</td>
<td>5.9%</td>
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<tr>
<td>IT</td>
<td>UIC 2007</td>
<td>12.1%</td>
<td>10.0%</td>
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<td>14.7%</td>
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<tr>
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<td>0.0%</td>
<td>75.2%</td>
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<td>24.3%</td>
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</tr>
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<td>UIC 2007</td>
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<td>0.0%</td>
<td>51.1%</td>
<td>9.2%</td>
<td>9.5%</td>
<td>6.2%</td>
</tr>
<tr>
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<td>EUROSTAT 2007a</td>
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<td>0.0%</td>
<td>0.3%</td>
<td>0.0%</td>
<td>99.6%</td>
<td>0.1%</td>
</tr>
<tr>
<td>PL</td>
<td>UIC 2007</td>
<td>93.8%</td>
<td>0.0%</td>
<td>1.8%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>4.4%</td>
</tr>
<tr>
<td>PT</td>
<td>EUROSTAT 2007a</td>
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<td>18.9%</td>
<td>29.2%</td>
<td>0.0%</td>
<td>19.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>SE</td>
<td>EUROSTAT 2007a</td>
<td>0.4%</td>
<td>0.9%</td>
<td>0.4%</td>
<td>45.7%</td>
<td>52.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>SI</td>
<td>UIC 2007</td>
<td>49.0%</td>
<td>1.0%</td>
<td>6.0%</td>
<td>30.0%</td>
<td>13.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>SK</td>
<td>UIC 2007</td>
<td>18.6%</td>
<td>2.4%</td>
<td>9.3%</td>
<td>55.7%</td>
<td>13.4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>UK</td>
<td>UIC 2007</td>
<td>33.7%</td>
<td>1.0%</td>
<td>36.6%</td>
<td>19.8%</td>
<td>5.0%</td>
<td>4.0%</td>
</tr>
</tbody>
</table>

*except Austria (Reference year 2006)
UIC 2007: railway mix, other sources: national mix

### Table 8  Energy efficiency and emission factors of the electricity supply for railway transport in European countries 2005*

<table>
<thead>
<tr>
<th>Country</th>
<th>Share CHP**</th>
<th>Efficiency</th>
<th>CO2 kg/kWh</th>
<th>NOx g/kWh</th>
<th>SO2 g/kWh</th>
<th>NMVOC g/kWh</th>
<th>PM10 g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>80%</td>
<td>83%</td>
<td>0.067</td>
<td>0.076</td>
<td>0.053</td>
<td>0.029</td>
<td>0.017</td>
</tr>
<tr>
<td>BE</td>
<td>21%</td>
<td>31%</td>
<td>0.253</td>
<td>0.490</td>
<td>0.800</td>
<td>0.051</td>
<td>0.045</td>
</tr>
<tr>
<td>CH</td>
<td>100%</td>
<td>56%</td>
<td>0.005</td>
<td>0.019</td>
<td>0.014</td>
<td>0.004</td>
<td>0.012</td>
</tr>
<tr>
<td>CZ</td>
<td>34%</td>
<td>34%</td>
<td>0.565</td>
<td>1.136</td>
<td>1.185</td>
<td>0.017</td>
<td>0.060</td>
</tr>
<tr>
<td>DE</td>
<td>21%</td>
<td>31%</td>
<td>0.592</td>
<td>0.548</td>
<td>0.483</td>
<td>0.057</td>
<td>0.052</td>
</tr>
<tr>
<td>DK</td>
<td>74%</td>
<td>60%</td>
<td>0.346</td>
<td>0.381</td>
<td>0.576</td>
<td>0.053</td>
<td>0.027</td>
</tr>
<tr>
<td>ES</td>
<td>24%</td>
<td>37%</td>
<td>0.480</td>
<td>1.644</td>
<td>4.577</td>
<td>0.069</td>
<td>0.212</td>
</tr>
<tr>
<td>FI</td>
<td>41%</td>
<td>40%</td>
<td>0.384</td>
<td>0.437</td>
<td>0.313</td>
<td>0.125</td>
<td>0.018</td>
</tr>
<tr>
<td>FR</td>
<td>41%</td>
<td>28%</td>
<td>0.069</td>
<td>0.211</td>
<td>0.304</td>
<td>0.023</td>
<td>0.024</td>
</tr>
<tr>
<td>HU</td>
<td>23%</td>
<td>28%</td>
<td>0.499</td>
<td>0.952</td>
<td>3.766</td>
<td>0.206</td>
<td>0.096</td>
</tr>
<tr>
<td>IT</td>
<td>28%</td>
<td>36%</td>
<td>0.640</td>
<td>1.112</td>
<td>2.533</td>
<td>0.182</td>
<td>0.169</td>
</tr>
<tr>
<td>LU</td>
<td>0%</td>
<td>24%</td>
<td>0.755</td>
<td>0.875</td>
<td>0.276</td>
<td>0.338</td>
<td>0.025</td>
</tr>
<tr>
<td>NL</td>
<td>63%</td>
<td>45%</td>
<td>0.407</td>
<td>0.580</td>
<td>0.408</td>
<td>0.059</td>
<td>0.037</td>
</tr>
<tr>
<td>NO</td>
<td>0%</td>
<td>91%</td>
<td>0.006</td>
<td>0.017</td>
<td>0.009</td>
<td>0.003</td>
<td>0.015</td>
</tr>
<tr>
<td>PL</td>
<td>23%</td>
<td>29%</td>
<td>0.986</td>
<td>1.785</td>
<td>7.138</td>
<td>0.048</td>
<td>0.434</td>
</tr>
<tr>
<td>PT</td>
<td>17%</td>
<td>36%</td>
<td>0.635</td>
<td>1.846</td>
<td>4.524</td>
<td>0.197</td>
<td>0.139</td>
</tr>
<tr>
<td>SE</td>
<td>72%</td>
<td>43%</td>
<td>0.015</td>
<td>0.037</td>
<td>0.048</td>
<td>0.007</td>
<td>0.012</td>
</tr>
<tr>
<td>SI</td>
<td>0%</td>
<td>30%</td>
<td>0.716</td>
<td>1.702</td>
<td>11.818</td>
<td>0.042</td>
<td>0.314</td>
</tr>
<tr>
<td>SK</td>
<td>59%</td>
<td>33%</td>
<td>0.186</td>
<td>0.678</td>
<td>0.861</td>
<td>0.057</td>
<td>0.168</td>
</tr>
<tr>
<td>UK</td>
<td>7%</td>
<td>33%</td>
<td>0.569</td>
<td>1.040</td>
<td>1.442</td>
<td>0.071</td>
<td>0.108</td>
</tr>
</tbody>
</table>

* including Combined Heat and Power (CHP)
** Share of electricity generation in CHP produced thermal on total (conventional) thermal electricity production in 2003 /Eurelectric 2005/
4.2 Transport modes

4.2.1 Road transport

The energy consumption of road transport depends on various factors. The following aspects are of significant importance:

- vehicle size and weight, vehicle configuration (trailer), motor concept, transmission
- weight of load (load factor)
- driving pattern: influence of the driver and of the road characteristics (road category, number and width of lines, curves, gradient).

In EcoTransIT international long distance transports are focussed on. These are typically accomplished using truck trains and articulated trucks with a gross weight of 40 tons. For feeding or special transports also other lorry types are used. In EcoTransIT the following gross weight classes are defined which cover all vehicle sizes used for cargo transport:

- Lorry < 7,5 gross tons (load capacity: 3,5 tons)
- Lorry or train 7,5 - 28 gross tons (load capacity: 12 tons)
- Truck train or articulated truck 28 - 40 gross tons (load capacity: 26 tons)
- Sweden and Finland truck train 40 - 60 gross tons (load capacity: 38 tons)

Besides the vehicle size, the emission standard of the vehicle is an important criterion for the emissions of the vehicle. In European transport, different standards (EURO 1 EURO 5) are in use. These standards can be selected. The Pre-EURO 1-standard is not relevant anymore for most long distance transports, and was therefore not included.

The influence of the load factor is modelled according to the differentiated values in the Handbook of Emission Factors /INFRAS 2004/. Accordingly, the fuel consumption of an empty vehicle can be 1/3 below the fuel consumption of the fully loaded vehicle. This influence can be even stronger depending on the driving characteristics and the gradient. The following figure shows an example for the energy consumption per vehicle-km and per ton-km as a function of load factor.
Energy consumption and emissions also depend on the driving pattern. Two typical driving patterns, one for highway traffic and one for traffic on other extra-urban roads, are considered by EcoTransIT. Traffic on urban roads is almost irrelevant in long distance transport and therefore not taken into account.
Another parameter is the **gradient**. Similar to rail transport, the gradient takes into account country-specific factors which represent the average topology of the country ("flat", "hilly", "mountains"). IFEU and INFRAS analyses for Germany /IFEU 2002b/ and Switzerland /INFRAS 1995/ show 5-10% higher energy consumption and emissions for heavy duty vehicles if the country specific gradients are taken into account. No significant differences could be determined between the countries of Germany and Switzerland. For these analyses, however, the entire traffic on all roads has been considered.

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

The energy and emission factors of road transport for EcoTransIT are derived from the Handbook of Emission Factors (HBEFA 2.1) /INFRAS 2004/. The values were compared with the new COPERT 4 model /LAT 2006/, which uses the same data base from the ARTEMIS project /ARTEMIS 2006/ as HBEFA 2.1. Therefore only very small differences between COPERT 4 and HBEFA 2.1 were found. This means that the values of HBEFA 2.1 are still up to date.

Normally emission factors for SO₂ are derived from the actual sulphur content of the fuel. Because of a lack of appropriate data the sulphur content is assumed to be 10 ppm in Germany. For all other countries the current European limit value of 50 ppm is used.
Table 9  Total emissions factors (operation & prechain) for lorry transport (articulated truck >34-40 t, motorway, average gradient for hilly countries)

<table>
<thead>
<tr>
<th>Emission standard</th>
<th>type of cargo</th>
<th>EC (kJ/tkm)</th>
<th>CO₂ (g/tkm)</th>
<th>NOₓ (mg/tkm)</th>
<th>NMHC (mg/tkm)</th>
<th>PMₐₐₙ (mg/tkm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro 1</td>
<td>bulk</td>
<td>981</td>
<td>65</td>
<td>610</td>
<td>65</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>1.086</td>
<td>72</td>
<td>683</td>
<td>75</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>volume</td>
<td>1.673</td>
<td>111</td>
<td>1.051</td>
<td>131</td>
<td>37</td>
</tr>
<tr>
<td>Euro 2</td>
<td>bulk</td>
<td>946</td>
<td>63</td>
<td>664</td>
<td>47</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>1.044</td>
<td>69</td>
<td>755</td>
<td>55</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>volume</td>
<td>1.592</td>
<td>106</td>
<td>1.192</td>
<td>91</td>
<td>18</td>
</tr>
<tr>
<td>Euro 3</td>
<td>bulk</td>
<td>976</td>
<td>65</td>
<td>492</td>
<td>46</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>1.082</td>
<td>72</td>
<td>553</td>
<td>54</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>volume</td>
<td>1.665</td>
<td>111</td>
<td>856</td>
<td>93</td>
<td>22</td>
</tr>
<tr>
<td>Euro 4</td>
<td>bulk</td>
<td>947</td>
<td>63</td>
<td>314</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>1.050</td>
<td>70</td>
<td>353</td>
<td>59</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>volume</td>
<td>1.616</td>
<td>107</td>
<td>544</td>
<td>102</td>
<td>4</td>
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<tr>
<td>Euro 5</td>
<td>bulk</td>
<td>899</td>
<td>60</td>
<td>184</td>
<td>50</td>
<td>2</td>
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<td>average</td>
<td>996</td>
<td>66</td>
<td>205</td>
<td>58</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>volume</td>
<td>1.532</td>
<td>102</td>
<td>315</td>
<td>100</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: Handbook of Emission Factors (INFRAS 2004), Copert 4 (LAT 2006), ARTEMIS (ARTEMIS 2006), IFEU estimation

Truck train with 60 tons gross weight in Finland and Sweden

The total gross weight allowance for truck trains in Sweden in Finland is 60 t and therefore about 20 t higher than in most other European countries. No values for energy consumption and emission factors for these trucks trains are included in the Handbook /INFRAS 2004/. According to the NTM values, a 60 t truck train is about 10 % more efficient (per tkm) in comparison with the 40 t truck train. The NTM values were compared with the values of the COPERT 4 model /LAT 2006/, which indicates an energy consumption for 60 t trucks, which is 30% higher than for 40 t trucks and emission factors, which are between 20% and 36% higher. Due to the higher load capacity the specific values per tkm for the 60 t truck are about 10% lower, which correlates very well with the NTM approach. Therefore, the specific energy and emission values per tkm for the 60 t truck are set 10 % lower than for the 40 t truck.

4.2.2 Rail transport

The main influencing factors for rail transport regarding energy consumption are:
• traction type (diesel, electric)
• train length and total weight
• proportion of load weight to empty weight of wagons and transport vessel
• route characteristics (gradient)
• driving behaviour (speed, acceleration) and air resistance.

The main indicator for calculating energy and emissions of rail transport is the energy consumption of the total train depending on the gross weight of the train.

**Gross ton weight of train**

Different railway companies have been interviewed for an appraisal of a typical train length for international transport /Railway companies 2002/. The railway companies state 1'000 t as a typical average gross weight for international trains. The maximum gross weight for international traffic is up to 2'000 t. Thus we estimate the gross weight of a long and therefore more energy efficient train to be around 1'500 t. The gross weight of short trains has been estimated to be around 500 t.

**Energy consumption**

Different average energy consumption data are available which already include the influence of these parameters, such as

• average annual consumption of typical freight transport by different companies.
• energy functions for specific energy consumption of rail transport /IFEU 1999/, /TEMA 2000/, /OMIT 2001/.

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

Due to the lack of more recent data EcoTransIT uses the same functions which have already been derived for the OMIT project /OMIT 2001/. No significant discrepancies have been found in an analysis of the average energy consumption of different railway companies /Railway companies 2002/. The functions are shown in the following figure.
Figure 5  Functions for the energy consumption of electric trains

Table 10  Specific final energy consumption for electric trains

<table>
<thead>
<tr>
<th>Wh/ktm</th>
<th>Flat</th>
<th>Hilly</th>
<th>Mountain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Train</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(500 t)</td>
<td>Bulk</td>
<td>40.2</td>
<td>50.3</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>48.3</td>
<td>60.4</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>60.4</td>
<td>75.5</td>
</tr>
<tr>
<td>Average Train</td>
<td>Bulk</td>
<td>28.5</td>
<td>35.6</td>
</tr>
<tr>
<td>(1.000 t)</td>
<td>Average</td>
<td>34.2</td>
<td>42.7</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>42.7</td>
<td>53.4</td>
</tr>
<tr>
<td>Long Train</td>
<td>Bulk</td>
<td>23.2</td>
<td>29.0</td>
</tr>
<tr>
<td>(1.500 t)</td>
<td>Average</td>
<td>27.9</td>
<td>34.9</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>34.9</td>
<td>43.6</td>
</tr>
</tbody>
</table>

Energy consumption of diesel trains

The available energy data for diesel traction ranges between 2.6 and 9.7 g/gross-ton-km /Railways companies 2002/. The statistical uncertainties can be due to unreliable
allocation of the fuel consumption to different users (passenger and goods transport, shunting, etc.). This study therefore uses the method of /OMIT 2001/: The primary energy consumption of diesel traction is estimated on the basis of the primary energy consumption of electro traction. This procedure can be used, because the total efficiency of diesel traction (including the production of fuel) is similar to the total efficiency of electro traction (including electricity generation).

So the same functional dependence as for electric traction is taken and has to be divided by the efficiency of the diesel-electric conversion of about 37%.

**Figure 6  Energy consumption of diesel trains**

![Energy consumption of diesel trains](image)

Source: OMIT 2001

**Emission factors for diesel trains**

Different from electro traction, emissions for diesel traction are also produced during the operation of the vehicle. These emission factors are stated as fuel consumption specific values (in g/kg diesel fuel). This study uses the values which have been made available by several railway companies /Railway companies 2002/. Default values have been defined for all other railway companies and are used for further calculations. Table 12 summarises the emission factors for diesel trains of different railway companies.
Table 11  Emission factors for diesel trains

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>NOx</th>
<th>SO₂</th>
<th>NMHC</th>
<th>PMdir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Cargo</td>
<td>3'170</td>
<td>70</td>
<td>0.01</td>
<td>2.8 (HC)</td>
<td>1.8</td>
</tr>
<tr>
<td>DB</td>
<td>3'175</td>
<td>55.0</td>
<td>0.02</td>
<td>5.7</td>
<td>1.74</td>
</tr>
<tr>
<td>DSB</td>
<td>3'170</td>
<td>56.7</td>
<td>0.07</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>TI</td>
<td>3'100</td>
<td>60</td>
<td>0.1</td>
<td>4.9</td>
<td>5.0</td>
</tr>
<tr>
<td>SNCF</td>
<td>3'150</td>
<td>39.6</td>
<td>0.1</td>
<td>4.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Default</td>
<td>3'170</td>
<td>55</td>
<td>0.1</td>
<td>4.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Source: different Railway companies, IFEU-estimation

Allocation methodology for rail transport

The allocation of energy consumption for the transport of a special cargo is easy if the total train transports only one type of cargo. To determine the energy consumption and the emissions of the rail transport of one loading unit in a single wagon train, the energy consumption of the total train is allocated to the individual loading units such that

- different energy consumptions for loading units with differing sizes and differing total weight are considered,
- the sum of all energy consumptions of individual loading units equals the total energy consumption/emissions of the entire train.

In the following, two different methodologies are presented.

Allocation according to “Mobilitäts Bilanz“ (also used in EcoTransIT)

In the DB study “Mobilitäts Bilanz“ /IFEU 1999/ the average train was defined as a train with a constant gross weight that is equal for the transport of various types of cargo. In consequence, the energy consumption per gross ton-km was used for all types of cargo in the train. The data required to calculate energy consumption per net ton-km of the specific cargo are:

- the gross ton weight of the total train
- the gross ton weight of the wagons with specific cargo
- the net weight of the specific cargo
With this methodology, the information about the empty weight of the train is not required. The result is the same for a long train with volume good or with a high share of empty wagons and a short train with bulk good, if both trains have the same gross ton weight.

**Allocation according to „Block Train“**

The second methodology defines the average train as a train with a constant empty weight of wagons, and so with the same number of wagons, a typical “block train configuration”. If the weight of cargo varies, the gross ton weight of the train changes and, in consequence, the energy consumption per gross ton-km changes.
This methodology was used for example in the IRU-study for trains of combined transport /IFEU 2000/.

The following figure shows possible results of the two methodologies: specific energy consumption per net-tkm dependent on load weight (in percent of the maximum load weight).

The consequence of the first methodology (gross weight of train constant) is a lower energy difference between bulk goods (high cargo weight) and volume good (low cargo weight). The second methodology has higher differences in energy consumption between bulk and volume good. It is more similar to the lorry transport, which has the highest differences in energy consumption depending on load weight.
Figure 9  Comparison of energy allocations with lorry values dependent kind of good

Comparison of energy allocations with lorry values
in MJ/gross-tkm

Comparison of energy allocations with lorry values
in MJ/Net-tkm
Which methodology is more realistic?

For an average approach which is chosen in EcoTransIT it is difficult to decide which methodology is the more realistic approach: For a block train the decision is easy. For a normal train the methodology of Mobilitäts-Bilanz is more realistic, if the composition of a train with light goods contains more wagons than a train with bulk goods, which was the implicit assumption in “Mobilitäts-Bilanz”.

We propose to use the methodology of “Mobilitäts Bilanz” for EcoTransIT, because it characterises the more common situation, whereas “Block train” is a special kind of train.

4.2.3 Sea transport

There are three categories of sea ships, which take into account size and capacity utilisation, and thus also the specific energy consumption and resultant emissions /Borken 1999/:

- **General cargo vessels, Ro-Ro-vessel and containerships**: these vessels have a load carrying capacity of 9,000 t to 23,000 t and operate more or less at full capacity on all trips. Ro-Ro-vessels are employed for short ferry boat trips.
- **Bulk cargo vessels**: these have an average load carrying capacity of around 40,000 t; they often operate at full capacity one way and return empty.
- **Tankers**: tankers are usually used for the transport of petroleum and have a load carrying capacity of 50,000 t to 200,000 t. They usually operate either at zero or full capacity.

Energy consumption and emission factors

In order to determine energy consumption and emissions of sea transport, in /Borken 1999/ several international sources were analysed. Regarding the energy consumption of different types of ships, the following ranges were obtained:

<table>
<thead>
<tr>
<th>Table 12 Energy consumption (crude oil) of sea ships</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ship type</strong></td>
</tr>
<tr>
<td>General cargo vessels</td>
</tr>
<tr>
<td>Bulk cargo vessels</td>
</tr>
<tr>
<td>Tankers</td>
</tr>
</tbody>
</table>

Source : Borken 1999 (different international studies)

From these values we estimate the following figures for the three types of cargo in EcoTransIT:
### Table 13  Energy consumption (crude oil) of sea ships for three types of cargo

<table>
<thead>
<tr>
<th>Ship type / cargo specification</th>
<th>g/tkm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk (heavy) cargo</td>
<td>2</td>
</tr>
<tr>
<td>Average cargo</td>
<td>4</td>
</tr>
<tr>
<td>Volume (light) cargo</td>
<td>7</td>
</tr>
</tbody>
</table>

Source: IFEU-Estimation based on Borken 1999 (different international studies)

The emission factors are also taken from /Borken 1999/. They are summarised in the following table.

### Table 14  Emission factors for sea ships

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>NOx</th>
<th>SO₂</th>
<th>NMHC</th>
<th>PM\textsubscript{dir}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea ship</td>
<td>3’185</td>
<td>84</td>
<td>80</td>
<td>2.4</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Source: Borken 1999 (different international studies)

### Allocation method for ferries

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

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

The following average values have been calculated according to this method for the concrete example of the Scanlines ferry:

- Lorry (30 gross tons) 27 g/gross-ton-km
- Railcar (46 gross tons) 22 g/gross-ton-km

These values are taken and differentiated according to vehicle types and kind of good. The resulting specific energy values are summarised in the following table.
Table 15  Specific Energy Consumption for ferries

<table>
<thead>
<tr>
<th>g/tkm</th>
<th>Rail</th>
<th>Lorry &lt;7,5t</th>
<th>Lorry &lt;28t</th>
<th>Lorry &lt;40t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk (heavy)</td>
<td>37</td>
<td>75</td>
<td>63</td>
<td>49</td>
</tr>
<tr>
<td>Average</td>
<td>45</td>
<td>87</td>
<td>72</td>
<td>55</td>
</tr>
<tr>
<td>Volume (light)</td>
<td>56</td>
<td>139</td>
<td>112</td>
<td>79</td>
</tr>
</tbody>
</table>

Source: Bäckström 2003, IFEU-assumptions

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

Emission factors for ferries

Ferries operate almost exclusively with medium speed engines usually running on gas oil/marine diesel oil. In EcoTransIT we use the NTM values. According to Bäckström 2003/, the sulphur content in Sweden is around 0.5-1%. This fuel, however, commonly has a sulphur content of up to 3%. We therefore use an average value of 1.5 % in this study.

Table 16  Emission factors for ferries

<table>
<thead>
<tr>
<th>g/kg</th>
<th>CO₂</th>
<th>NOₓ</th>
<th>SO₂</th>
<th>NMHC</th>
<th>PMₐir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferries</td>
<td>3’100</td>
<td>70</td>
<td>30</td>
<td>0.98</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: NTM, Estimation for SO₂

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4.2.4 Inland waterway transport

As for other means of transport, energy consumption and emissions of inland navigation vessels depend on parameters such as size (load capacity), motor power, engine technology and engine utilisation. These in turn correlate with the age of the ship, the load factor and the water flow conditions. For a detailed analysis, at least the main factors should be considered, which are ship size, load factor and water flow conditions. This, however, is possible only to a limited extent /Borken 1999/.

Energy consumption

Energy values for inland ship transport are available for

- different ship classes
- different operation conditions upstream/downstream, free-flow/with sluices

The following table is derived from an IFEU investigation based on different national and international sources /Borken 1999/.

Table 17  Energy consumption of inland ships dependent on ship size and type of waterway

<table>
<thead>
<tr>
<th>operation condition</th>
<th>Free flow</th>
<th>With sluices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>down-</td>
<td>down-</td>
</tr>
<tr>
<td>Ship type (payload)</td>
<td>stream</td>
<td>stream</td>
</tr>
<tr>
<td></td>
<td>upstream</td>
<td>upstream</td>
</tr>
<tr>
<td>Empty ship</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 t g/km</td>
<td>2'740</td>
<td>3'442</td>
</tr>
<tr>
<td>1'250 t g/km</td>
<td>3'770</td>
<td>4'754</td>
</tr>
<tr>
<td>1.750 t g/km</td>
<td>4'871</td>
<td>6'112</td>
</tr>
<tr>
<td>2.500 t g/km</td>
<td>5'643</td>
<td>7'072</td>
</tr>
<tr>
<td>Load factor 50 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 t g/tkm</td>
<td>7.7</td>
<td>4.4</td>
</tr>
<tr>
<td>1'250 t g/tkm</td>
<td>6.8</td>
<td>4.0</td>
</tr>
<tr>
<td>1.750 t g/tkm</td>
<td>6.3</td>
<td>3.7</td>
</tr>
<tr>
<td>2.500 t g/tkm</td>
<td>5.2</td>
<td>3.0</td>
</tr>
<tr>
<td>Load factor 100 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 t g/tkm</td>
<td>4.4</td>
<td>7.0</td>
</tr>
<tr>
<td>1'250 t g/tkm</td>
<td>4.0</td>
<td>6.1</td>
</tr>
<tr>
<td>1.750 t g/tkm</td>
<td>3.7</td>
<td>5.6</td>
</tr>
<tr>
<td>2.500 t g/tkm</td>
<td>3.0</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Source: Borken 1999 based in different international sources

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For EcoTransIT, specific energy values are required for an average ship in three operating conditions: no stream, upstream and downstream, as well as for three types of cargo. Three assumptions are made in this regard:

- For a typical ship, a vessel of the Europe type with a load carrying capacity of up to 1,250 t is used.
- For the operating conditions “upstream” and “downstream”, the respective mean values for free flow and barrage regulated / with sluices conditions are used.
- For non-flowing watercourses, the mean value of barrage regulated, upstream and downstream conditions is used.

When differentiating between the three types of cargo with regard to the energy consumption, it must be taken into consideration that empty trips are usually made against the course of the actual transport: an empty return trip following a transport upstream will therefore be downstream. In the calculations of the energy consumptions, this was taken into account by assigning the assumed empty trip part of the calculation an energy consumption value according to the counter-direction. The consumption values thus determined are listed in the following table.

### Table 18  Energy consumption values for inland navigation

<table>
<thead>
<tr>
<th>g/tkm</th>
<th>Upstream</th>
<th>Downstream</th>
<th>No stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk (heavy)</td>
<td>9.6</td>
<td>7.0</td>
<td>7.2</td>
</tr>
<tr>
<td>Average</td>
<td>13.6</td>
<td>8.2</td>
<td>9.6</td>
</tr>
<tr>
<td>Volume (light)</td>
<td>22.9</td>
<td>12.6</td>
<td>15.8</td>
</tr>
</tbody>
</table>

Source: Borken 1999, IFEU-assumptions

The emission factors for inland ships were taken from /Borken 1999/. They are listed in the following table.

### Table 19  Emission factors for inland ships

<table>
<thead>
<tr>
<th>g/kg</th>
<th>CO₂</th>
<th>NOₓ</th>
<th>SO₂*</th>
<th>NMHC</th>
<th>PM_{dir}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland ships</td>
<td>3'175</td>
<td>60.0</td>
<td>2</td>
<td>4.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

* Limit value 2008: 1000ppm sulphur

Source: Borken 1999

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4.2.5 Aircraft transport

Air freight service includes inland courier flights by small propeller powered planes as well as intercontinental jet flights for the transport of complete technical assets. Predominantly perishable and expensive goods are transported, and almost exclusively piece goods. The goods are either transported in cargo planes or together with passengers in airliners /Borken 1999/.

Specific energy consumption and emissions of air cargo transport depend heavily on the length of the flight. This is because their values vary between different flight phases: thus for example the take-off has the highest specific energy demand. Its share of the total flight obviously declines as the length of the flight increases.

If cargo is transported along with passengers, the energy consumption must be split between them. This is done by taking into account the weight of the passengers.

In recent years, air transport saw continuous energy savings. The Deutsche Lufthansa indicates a decline for the energy consumption per tkm of about 20 % for the last 5 years. We consider it is justified to follow the information of the Deutsche Lufthansa, which currently gives a value of 182 g/tkm for 2006 /Lufthansa 2007/.

Mainly high value volume goods are shipped by air freight and the permissible maximum weight is limited. Therefore no other types of goods (bulk, average) will differentiated.

The emission factors are derived from TREMOD /IFEU 2005/. For SO₂ the sulphur content of kerosene is assumed to be 210 ppm.

Table 20  Emission factors for aircraft cargo transport (long distance flights)

<table>
<thead>
<tr>
<th>g/kg</th>
<th>CO₂</th>
<th>NOₓ</th>
<th>SO₂</th>
<th>NMHC</th>
<th>PMₐir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo air plane</td>
<td>3'154</td>
<td>16.1</td>
<td>0.4</td>
<td>0.62</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Source: Lufthansa 2004, TREMOD (IFEU 2005), IFEU estimations IFEU Heidelberg 2008
5 Appendix

5.1 Special features in the Expert mode

5.1.1 User Defined Load Factors and Empty Trips

The expert mode allows the input of individual load factors and empty trip shares for road, rail and inland ship transport. The user can chose the default values for bulk, average and volume freight and change this values individually. The calculation is made with the user defined assumptions.

The empty trip is defined as share of distance the vehicles run empty in context of the transport considered. The environmental impacts of the empty trip are added to the result.

Lorry

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

**Table 21  Capacity and load factors for different lorry types**

<table>
<thead>
<tr>
<th></th>
<th>Lorry &lt; 7.5 gross tons</th>
<th>Lorry or train 7.5 - 28 gross tons</th>
<th>Truck train or articulated truck 28 - 40 gross tons</th>
<th>Truck train 40 - 60 gross tons (Sweden and Finland)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (tons)</td>
<td>3.5</td>
<td>12</td>
<td>26</td>
<td>38</td>
</tr>
<tr>
<td>Load Factor (freight weight/capacity)</td>
<td>Freight weight (tons)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>0.35</td>
<td>1.2</td>
<td>2.6</td>
<td>3.8</td>
</tr>
<tr>
<td>30% (volume freight)</td>
<td>1.1</td>
<td>3.6</td>
<td>7.8</td>
<td>11.4</td>
</tr>
<tr>
<td>50%</td>
<td>1.75</td>
<td>6.0</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>58% (average freight)</td>
<td>2.0</td>
<td>7.0</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>100% (bulk freight)</td>
<td>3.5</td>
<td>12</td>
<td>26</td>
<td>38</td>
</tr>
</tbody>
</table>

Train

The load factor for trains originally is defined as relation net tons / gross tons. For a better comparison with road and ship transport the values are transformed to the relation freight load/capacity with the following default values for an average wagon:

Empty weight of wagon: 23 tons

Gross ton weight of wagon: 84 tons

Freight capacity: 61 tons

The following figure show a comparison of the load factors for freight trains, based on this key values.
Figure 10  Load factors for freight trains

The following chart shows the resulting specific energy consumption per tons km for a large train.

Figure 11  Specific energy consumption of freight trains
Inland Ship

The methodology for inland ships is the same as for road transport. The reference ship has a capacity of 1250t. Thus a load factor of 100% means a freight weight of 1250t.

Because of different directions of flow the calculation of empty trips is different from road and rail transport: If the transport goes against the streaming, the empty trip is estimated as trip in streaming direction and inverse. For a transport without streaming the empty trip is also estimated without streaming.

5.1.2 Container transport

EcoTransIT allows the user input “number of TEUs”. For the emission calculation TEU is recalculated to tons, dependent on the kind of freight, based on the following information:

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Volume</th>
<th>Empty weight</th>
<th>Net load</th>
<th>Maximum gross mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>20’ (6,096 m)</td>
<td>8’ (2,438 m)</td>
<td>8’, 6” (2,591 m)</td>
<td>33,2 m³</td>
<td>2,250 kg</td>
<td>21,750 kg</td>
<td>24,000 kg</td>
</tr>
<tr>
<td>40’ (12,192 m)</td>
<td>8’</td>
<td>8’ 6”</td>
<td>67,7 m³</td>
<td>3,780 kg</td>
<td>26,700 kg</td>
<td>30,480 kg</td>
</tr>
</tbody>
</table>


For Ecotransit average values are needed which covers the 20’ container as well as the 40’ container. To cover all limitations, the following average values for the calculation are proposed:

<table>
<thead>
<tr>
<th>Kind of Freight</th>
<th>Empty weight</th>
<th>Net load</th>
<th>Gross mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk</td>
<td>2’000 kg</td>
<td>12’000 kg</td>
<td>14’000 kg</td>
</tr>
<tr>
<td>average</td>
<td>2’000 kg</td>
<td>7’000 kg</td>
<td>9’000 kg</td>
</tr>
<tr>
<td>volume</td>
<td>2’000 kg</td>
<td>3’600 kg</td>
<td>5’600 kg</td>
</tr>
</tbody>
</table>

5.1.3 Intermodal transfer

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

Container: The energy used by handling container in a rail cargo transport centre was estimated by /IFEU°2000/ with 4.4 kWh per transfer process. In other previous studies /ISV°1993, IFEU°1999/ a lower value (2.2°kWh/°transfer) for rail was assessed. For container transfer in ship cargo transport centres these studies searched out an energy factor twice than rail /ISV°1993/. Because of high uncertainties the value of 4.4 kWh per transfer process is taken for all carriers.

Liquid cargo: In /ISV°1993/ a very detailed calculation of the energy demanded by
transhipping diesel was carried out. For the different carriers the values range from 0.3 to 0.5 kWh/t, for which is why 0.4 kWh/t as average energy use is assessed.

Bulk cargo: The results of early IFEU-estimations searching out the energy use of unloading corn from different means of transport were used in /ISV°1993/. For bulk cargo transfer the previous value 1.3 kWh/t is also used in EcoTransIT.

Other cargo: In this category all cargo, which is not container, liquid or bulk cargo is summarised. Thus the value for energy use of transhipping cargo of this category has the highest uncertainty. On basis of /ISV°1993/ a factor of 0.6 kWh/t for this category is taken.

5.2 European mean values

EcoTransIT differentiates in its calculation many country specific parameters, such as the energy mix for electricity production and the road and rail gradient respectively. It also takes into account the type of transported goods (e.g. bulk, volume). For a superficial overview European mean values might be interesting. Therefore the following table shows the emissions per tkm caused by the average transport (average goods, average road and rail gradient, average energy split) in Europe.

Table 22 Average Emission factors for cargo transport within Europe (average goods, average road and rail gradient, average European energy split)

<table>
<thead>
<tr>
<th>Transport</th>
<th>EC</th>
<th>CO₂</th>
<th>NOₓ</th>
<th>SO₂</th>
<th>NMHC</th>
<th>Dust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road traffic*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&gt;34-40 t; Euro 3)</td>
<td>1'082</td>
<td>72</td>
<td>553</td>
<td>90</td>
<td>54</td>
<td>16</td>
</tr>
<tr>
<td>Rail transport**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average electric train</td>
<td>456</td>
<td>18</td>
<td>32</td>
<td>64</td>
<td>4</td>
<td>4.6</td>
</tr>
<tr>
<td>average diesel train</td>
<td>530</td>
<td>35</td>
<td>549</td>
<td>44</td>
<td>62</td>
<td>17</td>
</tr>
<tr>
<td>Air transport</td>
<td>9'876</td>
<td>656</td>
<td>3,253</td>
<td>864</td>
<td>389</td>
<td>46</td>
</tr>
<tr>
<td>Waterway (upstream/downstream)</td>
<td>727/438</td>
<td>49/29</td>
<td>839/506</td>
<td>82/49</td>
<td>84/51</td>
<td>26/16</td>
</tr>
</tbody>
</table>

* additional data see table 10
** based on the EU-27 energy split

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