Comparison of energy demand and emissions from road, rail and waterway transport in long-distance freight transport
Title of the study

Comparison of energy demand and emissions from road, rail and waterway transport in long-distance freight transport

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Authors:
Dr. Michael Spielmann
Dr. Michael Faltenbacher
Alexander Stoffregen
Diana Eichhorn

PE INTERNATIONAL GmbH
Hauptstraße 111 – 113
70771 Leinfelden – Echterdingen
Germany

Phone +49 (0) 711 341817 – 0
Fax +49 (0) 711 341817 – 25
Email info@pe-international.com
Internet www.pe-international.com
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<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGL</td>
<td>Bundesverband Güterkraftverkehr Logistik und Entsorgung (BGL) e.V. – German Federal Association of Road Haulage Logistics and Disposal</td>
</tr>
<tr>
<td>BMU</td>
<td>Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit – German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety</td>
</tr>
<tr>
<td>BMVBS</td>
<td>Bundesministerium für Verkehr, Bau und Stadtentwicklung – German Federal Ministry of Transport, Building and Urban Development</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CO₂ₑ</td>
<td>Carbon dioxide equivalent (consideration of the Kyoto gases with their respective equivalence factor, according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines, in particular carbon dioxide, methane, nitrous oxide and sulphur hexafluoride)</td>
</tr>
<tr>
<td>EU-27</td>
<td>European Union, a union of states consisting of 27 member states</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gases (Kyoto gases: CO₂, CH₄, N₂O, SF₆ and halogenated hydrocarbons)</td>
</tr>
<tr>
<td>gt</td>
<td>gross tonne: designation of the total train weight, including locomotive, wagons and load</td>
</tr>
<tr>
<td>HBEFA</td>
<td>Handbuch Emissionsfaktoren für den Straßenverkehr - Handbook on Emission Factors for the Street Transport</td>
</tr>
<tr>
<td>N₂O</td>
<td>Laughing gas, nitrous oxide – a greenhouse gas</td>
</tr>
<tr>
<td>NExBTL</td>
<td>NExBTL is a diesel fuel based on hydrogenated plant oil (here palm oil from Malaysia). The production technology is commercialised by Neste Oil (Finland)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Collective term for nitrogen oxides</td>
</tr>
<tr>
<td>PED</td>
<td>Primary energy demand</td>
</tr>
<tr>
<td>PM 2,5</td>
<td>Particulate matter emissions with a diameter of less than 2,5 µm</td>
</tr>
<tr>
<td>rel. to</td>
<td>relative to</td>
</tr>
<tr>
<td>SF₆</td>
<td>Sulphur hexafluoride</td>
</tr>
<tr>
<td>TEU</td>
<td>Twenty foot equivalent unit (equivalent to a 20-foot long container)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>tkm</td>
<td>Tonne-kilometres. Transport performance in the carriage of goods: transport of one tonne (1 t = 1000 kg) of goods over a distance of 1 kilometre (1 km).</td>
</tr>
<tr>
<td>Truck</td>
<td>Truck, in this study, is a heavy-duty vehicle with a gross vehicle weight rating of 40t</td>
</tr>
<tr>
<td>VBD</td>
<td>Versuchsanstalt für Binnenschiffbau e.V. – Research Institute for Inland Shipbuilding</td>
</tr>
<tr>
<td>VDA</td>
<td>Verband der Automobilindustrie - German Association of the Automotive Industry</td>
</tr>
<tr>
<td>vkm</td>
<td>Vehicle kilometre</td>
</tr>
<tr>
<td>Wh</td>
<td>Watt-hour: unit of energy.</td>
</tr>
</tbody>
</table>
Summary

The challenges of the climate change require considerable efforts in the transport sector. Transport is one of the main producers of greenhouse gases (GHG) and accounts for 23% of the CO2 emissions in Europe. (EU27). Unlike the other sectors the CO2 emissions of transport are still increasing, and continue to increase probably due to the expected growth of the volume of freight in future. So it is a matter of urgency to decouple growth and GHG emissions in the transport sector.

Because of these circumstances, it is imperative that the transport sector uses the best possible transport solution for climate protection. Until now, rail was commonly considered a better performer in the carriage of goods than road, which led to the conclusion that rail would be preferable to road in any case. In comparative studies, rail performs better than road by a factor of two to five. Generally written on behalf of rail companies or environment agencies, these studies raise questions regarding the chosen assumptions and boundary conditions. In general, the diesel consumption for fully loaded 40t trucks is assumed in a range from 39 to 46 l/100 km. But new available data shows that an average consumption of 30 l/100 km is a more realistic figure, why it is used in this study. This is based on simulations by car manufacturers and is validated through road testing by manufacturers and trade journals. Regarding the transport task consideration of important boundary conditions isn’t always done in a differentiated way.

In this comparative calculations between road, rail and, to a certain extent, inland waterway, a more precise and differentiated picture of the ecological impacts of each mode of transport is drawn and the specific advantages of each means of transport are demonstrated. This is necessary to identify the ecological best solution in each case.

In terms of Greenhouse Gas emissions (GHG-emissions), rail (and inland waterway) has clear advantages when transporting heavy bulk materials, e.g. iron cuttings. Rail and inland waterway are, in those cases, the ideal transport modes, and road transport is not a valid ecological alternative.

With the transport of heavy piece goods in a container (e.g. machine parts), the picture is different. In this case GHG emissions from road and rail lie within the same range. It turns out that the result of the comparison is sensitive to the boundary conditions selected for the transport task.

When considering long block trains (>20 loaded wagons and without empty trips, pre-carriage and on-carriage), rail shows lower GHG emissions than road. If, for production-related reasons (just-in-sequence), shorter trains (<10 loaded wagons) are required (e.g. intra-company transport Stuttgart-Rastatt), then road performs better than rail.

When considering the proportion of empty wagons and the pre-carriage and on-carriage routes of the train the results shift in favour of the road. If these preceding and succeeding routes amount to high proportion of the total distance, then a truck tends to show even better GHG values than a long block train.

In a general assessment of container transports that takes an average proportion of empty trips and an average utilization into account, rail shows better GHG values with long trains (40 wagons), which is the calculated average of the international combined transport.

Considering shorter trains (20 wagons), representing the calculated average of domestic combined transport, the emissions from road are comparable to rail.

With the transport of lighter goods, i.e. when volume instead of weight is the limiting factor, the results are quite comparable. Depending on the type of wagon road and rail show GHG emissions within the same range, when the train has between 5 and 15 wagons. In the case of lighter goods the type of wagon used is the determining factor of the GHG balance. In a direct comparison with sliding door wagons, a truck would only show lower GHG emissions against short trains with less than 6 wagons, but compared with container cars it is on a par with a train with 15 wagons, and compared with hopper wagons it still performs better than a train with 20 wagons.

Concerning future developments in the transport sector, the future rail power mix, the use of biofuels, new vehicle concepts (e.g. EuroCombi) and more stringent exhaust emission standards (Euro VI) are of vital importance to comparative studies. As there are still considerable uncertainties, only ranges of different scenarios can be modelled. Nevertheless, these show that an environmentally better rail power mix (with an increasing share of renewable energy until 2020) does not inevitably alter the results to the disadvantage of road transport. Road still remains a real alternative to rail for transport of heavy goods in a container. A high share of biofuels and the employment of EuroCombi vehicles can further improve the emissions balance of road transport, especially according to transport of lighter goods.

The detailed studies show that it is no longer possible to make general statements and that the validity of such general statements is limited. No mode of transport can be designated per se as the best environmental solution in the goods transport sector. The results indicate in which individual cases road, rail or inland waterway tend to be the most adequate means of transport. Only on the basis of such a differentiated assessment is it possible to select the most climate friendly option for each transport task. Forced by climate change and an exponentially growing volume of goods one has to choose the best possible solution. For this a study of individual cases for the respective transport task is required.
1 Introduction

1.1 Initial situation

In the current discussion on climate change, the transport sector is particularly criticised. The transport sector is responsible for 23% of the CO₂ emissions in Europe (EU27), which makes it a large contributor to greenhouse gas emissions. Moreover, and in contrast to other sectors, the CO₂ emissions from traffic continue to rise¹. Due to the projected growth in the volume of goods transport in Germany² and Europe, an increase in the transport sector’s percentage of greenhouse gas emissions has to be expected, at least under the present general conditions.

From today’s perspective, a large part of the goods transport growth will take place on the road³. The further shift of traffic from road to rail is frequently discussed as a strategy for reducing CO₂ and greenhouse gas emissions. This demand is based on the results of common transport studies that usually show significantly lower CO₂ emissions per transport service for rail than for road. According to DB Schenker⁴, the specific CO₂ emissions from road compared with rail are higher by about a factor of four. An even bigger advantage for rail results from a UBA (German EPA) study⁵ where its CO₂ emissions are rated better by a factor of five. In section 1.2, two other frequently cited sources are described in more detail. Summarising, we can say that the data sources underlying the calculation of CO₂ emissions in the goods transport sector are generally affected by railway companies (UIC – International Union of Railways) or environmental authorities (UBA – German Federal Environment Agency).

The German Railways make use of the results of these studies to justify further extension of the publicly financed railway infrastructure.

This is reflected in the development of the railway sidings. In the period of 2005/2006 there was an increase of 3%. However, in the period of 1999 to 2006 there was a significant decrease of 29%⁶.

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Furthermore, there is a trend in the logistics sector that in public tenders CO₂ emissions have to be disclosed along with the costs. Parts of the transport sector try to capitalize on the subject of CO₂ reduction by offering “CO₂-neutral services”. The media also frequently address the subject. The German business magazine Capital, for example, discusses CO₂ emissions as a future global currency.\(^7\)

**Conclusion:**

- There is an increasing demand for quantitative information on transport related CO₂/GHG emissions and other emissions with environmental impact.
- Recent publications and data sources are generally affected by railway companies or environmental authorities.

1.2 Published data and data sources

The results of a series\(^8\) of recently published comparative studies in the German magazine VerkehrsRundschau and a calculation done by the widely-used EcoTransIT\(^9\) tool, which are representative of the variety of published comparative studies on railway and road modes of transport, are discussed below.

1.2.1 CO₂ emissions calculation in the VerkehrsRundschau

Figure 1-1 shows a comparison between rail and road transport as it was published in VerkehrsRundschau, 2009, no. 42. Rail performs clearly better even when compared with a truck, labelled “well utilised” (factor 2). CO₂ emissions from a truck, labelled "poorly utilised", are almost 7 times higher.

![Figure 1-1: Comparison of the CO₂ emissions from truck and train, according to VerkehrsRundschau, 2009, no. 42](image-url)

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\(^7\) "CO₂ - die neue Währung", Capital Online, 30 November 2009. Available from: [http://www.capital.de/politik/100026641.html](http://www.capital.de/politik/100026641.html).


The values presented are the result of the following assumptions.

- Road transport: basic assumptions: 40-tonne truck, maximum payload: 25 t; consumption (with a capacity utilisation rate of 100%): 31.4 l/100 km; distance: approximately 800 km
  - Case 1: “poorly utilised”: seven pallets of 500 kg each, which results in a capacity utilisation rate by mass of 14%.
  - Case 2: “well utilised”: the seven pallets are co-loaded to a truck with an existing 11.5 t load. This results in a total payload of 15 t, which equates to a capacity utilisation rate by mass of 60%.

- Rail transport: seven pallets of 500 kg each are transported by a so-called average train. The calculation is performed using the EcoTransIT tool. It is based on a total train weight (wagons plus load, without locomotive) of 1000 gross tonnes. In addition, it is assumed that goods with low density are transported. Information on the type of wagon, capacity etc. is not provided.
1.2.2 CO₂ emissions calculation by EcoTransIT

Figure 1-2 shows a comparison between rail and road for heavy-goods transport, based on a calculation with EcoTransIT’s default values.\textsuperscript{10}

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{figure12.png}
\caption{Comparison of the CO₂ emissions between road and rail based on EcoTransIT’s default values}
\end{figure}

The values presented are the results of the following assumptions.

- Road transport: 40-tonne truck with an assumed consumption of approximately 39 l/100 km, as reported for motorways in HBEFA 2.1.\textsuperscript{11} Capacity utilisation rate is 100% and empty trip rate is 60%. This results in a theoretical total capacity utilisation rate of 63%.

- Rail transport: total train weight (wagons plus load, without locomotive) is assumed to be 1000 gross tonnes. For the wagons, EcoTransIT assumes a fixed empty weight of 23 t and a capacity of 61 t. The capacity utilisation rate for heavy goods is 100%\textsuperscript{12} with an empty trip rate of 80%, resulting in a theoretical total capacity utilisation rate of 56%.

**Conclusion:**

- In these studies, rail generally performs considerably better than road.
- However:
  - terminology and boundary conditions in *VerkehrsRundschau* should be critically examined.
  - based on updated knowledge, EcoTransIT’s assumption of the fuel consumption and share of empty trips are considered as too high.


\textsuperscript{11} In the methodology report (2008) of EcoTransIT no direct consumption value (i.e. l/100km) is documented. However, it is stated that HBEFA2.1. data has been employed. Test calculations with the online calculator (<http://www.ecotransit.org>; May 2009) resulted in higher diesel consumption values. The specific CO₂ emission of 60 g CO₂/tkm, as illustrated in the figure, is directly taken from the methodology report.

\textsuperscript{12} This capacity utilisation rate corresponds to a train length of 12 wagons.
2 Goal and Scope

2.1 Goal
The commissioner of this study is interested in an ecological comparison of the modes of transport for goods transport. Greenhouse gas emissions and other relevant emissions from long-distance freight transport on road, railway and inland waterway shall be analysed and compared with each other in detail.

The objective of the study is to examine the hypothesis: “In long-distance freight transport rail is always a better environmental solution than road.” For this purpose, the following items will be considered:

- validity analysis of results from recently published studies
- revaluation with current data and specific assumptions (based on logistics and means of transport)
- quantifiable assessment of future scenarios

2.2 Scope

2.2.1 Geographical scope of the study
The geographical scope of the study is Germany, including the national parts of international and transit traffic.

Important boundary conditions are the capacity utilisation rates of the individual modes of transport, the energy provision that underlies the electricity and fuel supply, and, where applicable, the diverted transport, pre-carriage and on-carriage.

2.2.2 Considered Emissions
Greenhouse gas emissions (GHG emissions) form the most relevant result parameter. They principally include CO₂, CH₄, N₂O and SF₆. Greenhouse gas emissions are grouped under the name CO₂e (CO₂ equivalent).

However, an exclusive consideration of greenhouse gases is not appropriate for a holistic assessment of the environmental friendliness of a service. It is imperative that climate related improvements are not carried out at the cost of other environmental impacts. Therefore, the following typical environmentally harmful emissions from transport will also be considered in this study:

- NOₓ emissions
- particulate matter (PM2.5) emissions
2.2.3 Life cycle approach

The basis of this study is the emissions from the actual operation of the modes of transport themselves and their preceding steps for the supply of energy carriers (all types of transport) and electricity generation.

The study is based on a holistic approach, i.e. not only the emissions from the actual operation of the transport mode are considered but also the ones resulting from the supply of energy carriers (i.e. electricity) and fuels.
3 Methodology and approach

In common literature, different reference units are used for the intermodal comparison of different modes of transport.

Frequently, comparisons are done by reference to general environmental indicators (e.g. kg of CO₂/tkm). Sometimes absolute emissions from typical transport relations are calculated in a further calculation step, in order to incorporate specific logistical aspects into the comparison.

In this study, the comparison of modes of transport is done on the basis of both specific environmental indicators and selected typical transport relations. It is also based on assumptions about technical characteristics of the means of transport and on specific boundary conditions regarding traffic situations.

In order to permit a transparent comparison, the simulation in this study is subdivided into three calculation levels.

- Environmental indicator - Mode of transport: description of technical and traffic-related functions for consumption and emissions
- Environmental indicator - Transport efficiency: consideration of general logistical aspects (average capacity utilisation rate and empty trip rate)
- Environmental impacts of specific transport services: consideration of specific logistical aspects for selected route examples (pre-carriage, main carriage and on-carriage distance)
In Figure 3-1 the three calculation steps and the main influencing factors are illustrated.

![Diagram showing calculation steps](image)

**Figure 3-1:** Calculation steps, reference units and main influencing factors

### 3.1 Environmental indicator - Mode of transport

In a first step, so-called environmental indicators will be developed separately for each of the relevant modes of transport. These environmental indicators specify the environmental impacts of a transport mode based on one vehicle kilometre (vkm). The important determining factors in the calculation are:

- technical characteristics of the vehicle like fuel consumption, after-treatment of exhaust gases, etc.
- operational profile/traffic situation (topography, average speed, etc.)
- supply of fuels (road and inland waterway) and electricity (for rail)

These environmental indicators and main assumptions are given in chapter 4.

### 3.2 Environmental indicator - Transport efficiency

Environmental indicators for transport efficiency (e.g. kg CO₂/ktkm) are based on the environmental indicator ‘mode of transport’. In addition, average assumptions about capacity (mass, volume) and payload (capacity utilisation) of the modes of transport will be included. Moreover, this indicator also comprises average assumptions about the empty trip rate.
3.3 Environmental impacts of specific transport services
The calculation of the environmental impacts of specific transport services is also based on the environmental indicator "mode of transport". In addition to the assumptions about capacity utilisation and empty trip rate, the actual transport distances for the main carriage and for the pre-carriage and on-carriage in combined transport will be included in the calculations for the comparison of means of transport.
4 Modes of transport

4.1 Road transport

4.1.1 Fuel consumptions and direct emissions

In German speaking countries, the HBEFA\textsuperscript{13}/PHEM\textsuperscript{14} is generally used as the data basis for calculating direct vehicle emissions from a truck in relation to the kilometres travelled (e.g. CO\textsubscript{2}/vkm). The HBEFA provides specific vehicle emission values for various parameters, like road class, traffic situation, weight category, Euroclass, etc. HBEFA data for specific parameter settings are also used in other studies in order to compare different modes of goods transport, e.g. EcoTransIT\textsuperscript{15}.

In Figure 4-1 fuel consumption data from various sources are illustrated. Besides the HBEFA data, truck manufacturer’s data based on test runs and simulations are documented specifically.

![Figure 4-1: Fuel consumption data on 40-tonne lorries at full load from various studies.\textsuperscript{16}]

The figure shows that for lorries the fuel consumption values based on the existent tools (HBEFA and EcoTransIT) are significantly higher that the values based on manufacturer’s measurements or test runs of independent professional journals.


\textsuperscript{15} EcoTransIT: Tool for quantification of emissions from freight transport. Developed by the Institute for Energy and Environmental Research (ifeu), Heidelberg, and Rail Management Consultants GmbH (RMCon), Hannover. - Available from: <http://www.ecotransit.org/>.

\textsuperscript{16} HBEFA data are based on the traffic situation „average motorway“: Ecotransit Online Calculator (www.ecotransit.org, May 2009) and own calculations. ‘Trucker test’ primary data are based on the study ‘Grüne Welle am Brenner’, Trucker - das Magazin für Fernfahrer, 2009, no. 8, pp. 32-41; ‘manufacturers’ primary data are based on truck manufacturer’s data from computer simulations validated with test runs; values for Euro IV are based on a manufacturer’s estimation of an additional consumption of 2%. Primary data from manufacturers is based on the utilisation of an aerodynamically optimised trailer, as available on the market.
As a logical consequence, the CO₂ emissions currently communicated are also higher (see chapter 1.2).

For the calculations in this study, the consumption of a 40-tonne truck meeting Euro V emission standards and at full load is assumed as 30 l/100 km. For a truck meeting Euro VI emission standards, a slightly higher consumption of 30.6 l/100 km is assumed. The data on NOₓ and particulate matter emissions were provided by the commissioner of this study, and for Euro V emission standards they coincide with the data available in the HBEFA. The environmental indicators used for road as transport mode are summarised in Table 4-1.

Table 4-1: Environmental indicators for the road as transport mode (40-tonne truck, at full load)

<table>
<thead>
<tr>
<th></th>
<th>GHG emissions 17 (g CO₂e/vkm)</th>
<th>Nitrogen oxides emissions (g NOₓ/vkm)</th>
<th>Particulate matter emissions (g PM2.5/vkm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro V</td>
<td>800</td>
<td>2.64</td>
<td>0.03</td>
</tr>
<tr>
<td>Euro VI</td>
<td>816</td>
<td>0.58</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Conclusion:

- For the calculations in this study, a fuel consumption of 30 l/100 km at full capacity utilisation (100%) by mass will be assumed.
- Greenhouse gas emissions of a Euro V truck at full load lie at 800 g CO₂e/vkm.
- Specific NOₓ-/PM emissions will be assumed as 2.6 g/vkm and 0.03 g/vkm, respectively, for a truck meeting Euro V standards, and as 0.5 g/vkm and 0.016 g/vkm, respectively, for a truck meeting Euro VI standards.

4.1.2 Life cycle emissions: supply of fuel and overall emissions

Figure 4-2 shows the greenhouse gas emissions (in kg CO₂e) of the supply of fuel related to one litre (1 l) of diesel fuel with an energy content 18 of 36 MJ/l, a so-called diesel equivalent. Besides the data for conventional diesel fuel, it also shows the emission values for a modern diesel fuel (a 6.25%19 blend with biofuels corresponding to the blending quota, as of 2010, in the updated Biofuel Quota Law 20). Because of their future potential, this study will only consider second generation biofuels, in this case NExBTL 21. Figure 4-2 also illustrates the emissions originating from the supply of a purely biogenic diesel fuel (again NExBTL).

---

17 based on 100% fossil diesel fuel
18 related to the net calorific value (NCV)
19 related to the energy content, equal to B7
21 NExBTL is a diesel fuel based on hydrogenated plant oil (here palm oil from Malaysia) with a higher cetane number than conventional diesel fuel. The production technology is commercialised by Neste Oil (Finland).
- Conventional supply of diesel fuel: consideration of the entire production chain (well-to-tank)\textsuperscript{22}
- NExBTL from palm oil: country of origin: Malaysia; from certified growing, i.e. no slash-and-burn in order to create croplands; transported by tanker (about 45 % of GHG emissions originate from the cultivation of the oil palms).\textsuperscript{23}

The sea transport of the malaysian sourced biofuel accounts for ~4% of the NO\textsubscript{x} of the pure NExBTL fuel.

Figure 4-2: Greenhouse gas emissions from the supply of fuel

Figure 4-3: NO\textsubscript{x} emissions from the supply of fuel

Figure 4-4 shows the overall GHG emissions per vkm, i.e. direct operating emissions and indirect emissions from the supply of fuel.

With the use of conventional diesel fuel, the supply of fuel has a share of 12% of the overall GHG emissions. This value rises slightly to 14% for a blend with 6.25% of biofuel.


\textsuperscript{23} Data are based on ifeu: An Assessment of Energy and Greenhouse Gases of NExBTL, Heidelberg, 2006, and own calculations in 2009. It is assumed that CH\textsubscript{4} emissions predominantly derive from the rotting of plant residues after oil milling, without CH\textsubscript{4} recovery. N\textsubscript{2}O derives from cultivation in palm oil plantations. Reference year: 2005.
This increase is based on the fact that the supply of biofuels is at first connected with higher GHG emissions than the supply of conventional diesel fuel from fossil oil (see Figure 4-2). The advantage of the use of biofuels reveals itself in the holistic assessment of supply and usage.

Figure 4-4: Overall GHG emissions per vkm (direct operating emissions during usage and indirect emissions from the supply of fuel)

The exclusive (100%) usage of NExBTL results in a halving of the GHG emissions because CO₂ emissions from the combustion of biofuels are assessed as CO₂ neutral, i.e. with a zero value, according to the specifications given in the EU Directive on Renewable Energy²⁴.

**Conclusion:**

- The supply of fuel has a share of 14% of the overall GHG emissions when diesel fuel with a share of 6.25% biofuel is used.
- The supply of biofuels is, at first, connected with higher GHG emissions than the supply of conventional diesel fuel from fossil oil. The advantage of the usage of biofuels reveals itself in a holistic assessment of supply and usage.

4.2 Railway transport

In this study, only the electric traction of freight trains will be considered\(^{25}\). Consequently, no direct emissions occur during operation, but GHG emissions and other environmentally relevant emissions occur in relation to the provision of the consumed electricity. They will be calculated from the following parameters:

- specific energy consumption (e.g. kWh/tkm)
- emissions from the supply of electricity (e.g. g CO\(_2\)e/kWh)

4.2.1 Specific energy consumption

The energy consumption per trailed gross tonne [Wh/gt] is used as the basis for calculating the specific energy consumption of rail transport. This allows the calculation of the specific energy consumption per tkm (E\(_s\)) as follows:

\[
E_s = \frac{E_{Bt}}{\text{payload (t)/train weight (gt)}}
\]

The data on the energy consumption per trailed gross tonne (E\(_{Bt}\)) were taken from EcoTransIT. The origin and quality of these data are difficult to assess. Obviously they are not primary data of a recent date. Some sources go back as far as the mid 80’s\(^{26}\).

4.2.2 Life cycle emissions: supply of electricity and overall emissions

For electricity, the emission factors (e.g. g CO\(_2\)e/kWh) will be used according to the factor for supply of power for traction, specified by the DB AG (German National Railway Company) and ifeu (ifeu - Institute for Energy and Environmental Research). The DB AG operates an own low-frequency-power network whose fuel mix distinguishes itself from the German grid mix by a higher share of renewable energy carriers. Therefore, the traction current mix causes slightly lower CO\(_2\) emissions than the "general" German power grid mix. Supply of the different energy carriers (hard coal, lignite, natural gas etc.) from various producing countries and their transformation in German power plants are also considered.

\(^{25}\) Diesel traction has been neglected because in Germany it only accounts for 4% and, therefore, plays a minor role. (DB Schenker - Klimaschutz durch CO\(_2\) freien Transport, Berlin, 2009.)


In this study, the supply of the traction current is based on a value of 641 g CO\textsubscript{2}e/kWh\textsuperscript{27}. The environmental indicators used for the German rail power mix are summarised in Table 4-2.

Table 4-2: Environmental indicators for the German rail power mix

<table>
<thead>
<tr>
<th></th>
<th>GHG emissions (g CO\textsubscript{2}e/kWh)</th>
<th>Nitrogen oxides emissions (g NO\textsubscript{x}/kWh)</th>
<th>Particulate matter emissions (g PM\textsubscript{2.5}/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rail power mix</td>
<td>641</td>
<td>0,52</td>
<td>0,018</td>
</tr>
</tbody>
</table>

Base year for the supply of power for traction is 2005.

**Conclusion:**

- Emissions from the supply of traction current according to EcoTransIT.
- Consideration of GHG emissions, not only CO\textsubscript{2} emissions.

\textsuperscript{27} based on the CO\textsubscript{2} value (592 g CO\textsubscript{2}/kWh) of the German rail power mix is 2005, from ifeu: EcoTransIT – Environmental methodology and data, Heidelberg, 2008, and on own calculations for the remaining greenhouse gases.
4.3 Inland waterway transport

Figure 4-5 shows the fuel consumption values obtained from different literature references for two representative vessel types. These examples refer to a capacity utilisation rate of 100% for a trip on a regulated river. The considerations in this study will be based on the VDB\textsuperscript{28} data and the emissions values of Planco\textsuperscript{29} because they are the most detailed. In ARTEMIS\textsuperscript{30} no distinction is made between downstream and upstream navigation, in EcoTransIT only a limited number of transport situations (upstream/downstream navigation on a flowing and regulated river) are modelled.\textsuperscript{31}.

![Figure 4-5: Fuel consumption (kg diesel fuel/vessel-km)](image)

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\textsuperscript{30} Paul Boulter and Ian McCrae TRL Limited et al., ARTEMIS: Assessment and reliability of transport emission models and inventory systems, European Commission, Brussels, 2002.

4.3.1 Fuel consumptions and direct emissions

The specific fuel requirement for inland vessels according to VBD\textsuperscript{32} is described as 0.2 kg diesel fuel/kWh engine power output. This allows the calculation of the fuel consumption as follows:

1. fuel consumption [kg/h] = special fuel consumption [kg/kWh] * installed propulsion power [kW] * utilisation ratio of propulsion power [%]

The utilisation ratio of the propulsion power depends on the waterway and the capacity utilisation of the vessel. The capacity utilisation is defined by the actual payload (causes actual draught) / maximum payload (maximum draught). It is shown, that the cargo capacity, especially of large motor vessels on smaller rivers, is limited due to draught or air-draught restrictions. The cruising speed relative to the ground is calculated from the flow velocity of the waterway. The VDB study provides data on the average speed of a selection of vessel types on rivers, regulated rivers and canals. The actual speed relative to the ground depends on whether the vessel is sailing upstream or downstream and is calculated as follows:

2. downstream (with the current): speed rel. to the ground = speed of vessel + flow velocity of the water

3. upstream (against the current): speed rel. to the ground = speed of vessel - flow velocity of the water

Diesel fuel consumption related to the sailed vessel-km is therefore calculated as follows:

4. fuel consumption [kg/km] = fuel consumption [kg/h] / speed rel. to the ground [km/h]

Fuel consumption related to the transport performance (tkm) is calculated by:

5. fuel consumption [kg/tpm] = (fuel consumption empty [kg/km] * capacity utilisation rate + fuel consumption empty [kg/km]) / (capacity utilisation rate * maximum dead weight capacity)

The direct emissions are calculated in accordance with Planco 2007\textsuperscript{33} for CO\textsubscript{2} as 630 g/kWh, for NO\textsubscript{x} as 8,81 g/kWh (Johann Welker, CEMT class IV) and 8,89 g/kWh (large motor vessel), and for particulate matter as 0,1 g/kWh (Johann Welker, CEMT class IV) and 0,13 g/kWh (large motor vessel). The emissions values used refer to the best available technology for cargo motor vessels in Germany in 2006.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Conclusion: & \\
\hline
- The specific consumption is similarly indicated in all sources (180-200g/kWh) & Variations arise from the required engine power in relation to heading and type of river. \\
- A capacity utilisation rate of 100\% for a large motor vessel is often not possible, & due to draught and/or air-draught restrictions. \\
\hline
\end{tabular}
\end{table}


4.3.2 Life cycle emissions: supply of fuel and overall emissions

Figure 4-6 shows the life cycle emissions profile of a large motor vessel with a capacity utilisation rate of 60% (1800 t, draught 2.50m) on downstream navigation (regulated river) and with an average speed relative to the ground of 18 km/h. It clearly illustrates that direct emissions from diesel fuel combustion cause most of the overall emissions. Consideration of diesel fuel supply for an inland vessel is carried out along the lines of the supply of diesel fuel for a truck, as described in chapter 4.1.2.

![Bar Chart]

**Figure 4-6:** Life cycle emissions from an inland vessel – separation between supply and usage of diesel fuel

**Conclusion:**
- From 2010 on, use of road diesel fuel (10 ppm sulphur content, 6.25% biofuel blend) in inland waterway transport.
- Percentages of PED and GHG emissions from the supply of diesel fuel are identical to the ones for road transport.

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5 Intermodal comparison

5.1 Selection of transport relations
The comparison of means of transport will be done by selected examples of transport relations, hereinafter also referred to as transport task. The examples presented have been agreed on by the commissioner of this study. The objective of this selection is to present and compare the broadest possible range of different transport services. A particular emphasis is placed on container transports.

As a general rule, in this study distinction will be made between

- transport of heavy goods
- transport of light goods.

The transport relations have been selected so that they can be served at least by rail and road. In selected cases inland waterway transport has also been included.

In order to ensure comparability of the means of transport, with some transport relations for rail and inland waterway transport the on-carriage and pre-carriage by a truck has been considered. In this context, it should again explicitly be stated that in reality the selected transport relations are not served by all three modes of transport, because usually only the most economic transport is used.

The reference unit is specifically stated for each case. In the case that for particular transport relations the distances to be covered by the different modes of transport should vary significantly, then, in the intermodal comparison, the overall emissions for the defined transport case will be given.

For the supply of fuels and the operation of the individual modes of transport, the relevant values and relations presented in chapter 4 will be used.

5.2 Transport of heavy goods

5.2.1 Transport task - Transport of heavy bulk goods
The comparison of GHG emissions from the transport of heavy\textsuperscript{35} bulk goods will be illustrated and discussed based on the following example.

Transport task: transport of cast iron borings (bulk density 2 t/m³), 1800 t, from Stuttgart to Rotterdam.

For the transport of heavy bulk goods (e.g. cast iron borings) rail or inland waterway are particularly suitable for economic reasons. The comparison with road is therefore done because of academic interest.

Since the distances to be covered by the modes of transport are significantly different, the overall emissions for the defined transport case will be indicated in the intermodal comparison.

\textsuperscript{35} In this study, the expression „heavy goods“ refers to the density of the transported goods. Goods with a density of 2 t/m³ (e.g. iron fillings, sand, iron ore) are referred to as heavy, whereas as goods with a density < 0.2 t/m³ (e.g. insulating material, aluminium swarf, wood chips) are referred to as „light goods“, in terms of classification.
The following assumptions have been made for the calculation.

- General assumptions:
  - no consideration of empty trips
  - no pre-carriage and on-carriage

- Specific assumptions for modes of transport:
  - road transport: truck with 40 t gross vehicle weight rating; capacity utilisation rate: 100%; distance: 615 km
  - rail transport: train with 27 hopper wagons; capacity utilisation rate: 100%; distance: 700 km
  - waterway transport: inland vessel with 60% capacity utilisation rate (due to draught restrictions on the Neckar river); distance: 785 km

Figure 5-1 illustrates the GHG emissions from the selected modes of transport during a transport of 1800 t of iron fillings.

![Figure 5-1: Comparison of GHG emissions during transport of heavy bulk goods from Stuttgart to Rotterdam](image)

With the transport of heavy bulk goods, the advantages of rail and inland waterway over road become apparent. While rail and inland waterway are approximately on a par, GHG emissions from road transport are more than twice as high. The good performance of rail compared with road is mainly due to the parameters ‘train length’ and ‘wagon type’. For example, for heavy bulk materials a hopper wagon with a payload of 66 t can be used.

In the modelling, emphasis was placed on equivalent amounts being transported. With a draught restriction of 2.5m on the Neckar river, a large motor vessel can only load 1800 t. This means a capacity utilisation rate of only 60%. This results in higher GHG emissions from the inland vessel.

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36 No further goods will be co-loaded on the Rhine river from Mannheim, although this would theoretically be possible. By this assumption the comparison between the individual modes of transport can be done for constant loads. Thus, in this transport task the inland vessel is not loaded to capacity. If in Mannheim the maximum payload of 3000 t would be fully utilised, GHG emissions from waterway transport would be reduced by approximately 20%.

37 Account has to be taken of the fact that for waterway transport the energetically and thus environmentally favourable case of downstream navigation has been assumed. An averaging of downstream and upstream navigation would result in an almost doubled fuel consumption and GHG emission value. This proportion also approximately applies to restricted emissions like NOx and particulate matter.
5.2.2 Transport task - Container transport of heavy piece goods

The comparison of GHG emissions from the transport of heavy piece goods in a container will be illustrated and discussed based on the following examples.

- Transport task 1: transport of engines and gear parts from Stuttgart to Bremen
- Transport task 2: transport of engines and gear parts from Stuttgart to Rastatt

Reference value: as the distances to be covered by the modes of transport are different, the overall emissions for the defined transport case will be indicated in the intermodal comparison.

5.2.2.1 Transport task 1: transport of engines and gear parts from Stuttgart to Bremen

The following assumptions have been made for the calculation.

- General assumptions:
  - no consideration of empty trips

- Specific assumptions for modes of transport:
  - road transport: truck, 30 l/100 km (at full load, average value for this study); distance: 633 km; capacity utilisation rate: 84%, related to the maximum payload (semi-trailer)
  - rail transport: block train (20 wagons); distance: 628 km; swap bodies containing a load of approximately 10.5 t each (92%, related to the maximum actual freight payload)

Figure 5-2 is a graphical comparison of the GHG emissions from the selected modes of transport for transport task 1.

![Graph showing GHG emissions comparison](image)

Figure 5-2: Comparison of the GHG emissions during intra-company transport of heavy piece goods from Stuttgart to Bremen

This transport task illustrates the advantages of rail over road in a transport with long block trains without empty wagons. The use of longer container wagons (3 instead of 2 TEU cargo capacity) results in a further reduction of GHG emissions of about 10% for rail. But, it is also evident that the differences between rail and road are much less dramatic than often advertised.
5.2.2.2 Transport task 2: transport of engines and gear parts from Stuttgart to Rastatt

The following assumptions have been made for the calculation.

- General assumptions:
  - 220 t, just-in-sequence delivery (twice per working day)
  - no consideration of empty trips

- Specific assumptions for modes of transport:
  - road transport: fuel consumption: 2 different cases:
    - a) truck, 30 l/100 km (at full use of capacity, average value for this study)
    - b) truck, 36 l/100 km (real consumption for the distance covered and actual capacity utilisation, demanding route)
  - distance: 115 km; capacity utilisation rate: 83% (semi-trailer)
  - rail transport: distance: 108 km; capacity utilisation rate: 73% (40 ft container); 6 wagons; pre-carriage: 2 km on the road

Figure 5-3 is a graphical comparison of the GHG emissions from the selected modes of transport.

![Comparison of GHG emissions (Figure 5-3)](image)

**Figure 5-3:** Comparison of the GHG emissions during intra-company transport of heavy piece goods from Stuttgart to Rastatt. The main carriage done by the train is shown in blue, the pre-carriage is in red.

From this case study it becomes apparent that despite a higher fuel consumption of 36 l/100km for the truck, rail performs worse than road in terms of GHG emissions. The fuel consumption of 36 l/100km for the truck is based on actually measured consumption for the demanding route between Stuttgart and Rastatt. On the contrary, greenhouse gas emission values from rail transport are based on an estimated average value of the energy consumption in Germany. For a better comparison, road transport will also be described here by an average consumption of 30 l/100 km. In this case, road compared with rail performs even better.

**Conclusion:**

- Transport of heavy piece goods in a container with a short block train (e.g. for production-related reasons) causes higher GHG emissions than road transport.
5.2.3 Sensitivity analyses for the transport of heavy piece goods in a container

In this section, the influence of pre-carriage, on-carriage and the proportion of empty wagons on the results of a rail-road comparison will be studied with the help of two sensitivity analyses.

- Sensitivity analysis 1: influence of pre-carriage and on-carriage distances on the comparison of rail and road for various train lengths.
- Sensitivity analysis 2: influence of the proportion of empty wagons on the comparison of rail and road for various train lengths.

5.2.3.1 Sensitivity analysis 1: influence of pre-carriage and on-carriage distances on the comparison of rail and road for various train lengths

The basic assumptions for the sensitivity analysis refer to the transport task Stuttgart – Rastatt. The following assumptions have been made for the calculation.

- General assumptions:
  - no empty trips are assumed for any of the considered modes of transport (i.e. only the one route Stuttgart – Rastatt is considered).
- Specific assumptions for modes of transport:
  - road transport: truck, 30 l/100 km at full load; capacity utilisation rate: 79%; max. payload 23 t
  - rail transport: block train without empty wagons; capacity utilisation rate: 73%

Reference value: for the intermodal comparison, the emissions will be related to one tonne of transported goods (i.e. in a model assumption the main carriage for road and rail is set to 1 km).

Figure 5-4 is a graphical comparison of the GHG emissions from the selected modes of transport per freight tonne.
In interpreting the results, it should be noted that an empty trip rate has not been considered either for rail or for road. Assuming that there is no difference in the empty trip rate of rail and road, the following statements on the influence of pre-carriage and on-carriage in relation to train length can be made:

- block train with 10 wagons: in this scenario rail shows higher emissions than road even with a direct rail link at the places of receipt and delivery.
- block train with 15 wagons: in this scenario road and rail are approximately on a par for a pre-carriage and on-carriage proportion of 5%. For a pre-carriage and on-carriage proportion higher than 10% of the main carriage distance, road shows a better GHG value.
- block train with 20 wagons: assuming a 0% empty trip rate of rail and road, rail performs better than road for a pre-carriage and on-carriage proportion of up to 10%. With a pre-carriage and on-carriage proportion of approximately 20% of the main carriage distance, road and rail are on a par.

5.2.3.2 Sensitivity analysis 2: influence of the proportion of empty wagons on the comparison of rail and road for various train lengths

The basic assumption of this sensitivity analysis is a transport of vendor parts from the catchment area of the Wuppertal-Langerfeld goods station (domestic transport) to the Mercedes-Benz Untertürkheim plant (near Stuttgart).

The following assumptions have been made for the calculation.

- General assumptions:
  - pre-carriage and on-carriage will not be considered.
Intermodal comparison

- Specific assumptions for modes of transport:
  - road transport: truck, 30 l/100 km; capacity utilisation rate: 80%; max. payload 25,7 t
  - rail transport: block train with 16 wagons; capacity utilisation rate: 80% 

Reference value: for the intermodal comparison, the emissions will be related to one tonne of transported goods (i.e. in a model assumption the main carriage for road and rail is set to 1 km).

Figure 5-5 is a graphical comparison of the GHG emissions from the selected modes of transport per freight tonne.

![Figure 5-5: GHG emissions in relation to the proportion of empty wagons (16 wagons loaded), pre-carriage and on-carriage](image)

Assuming a 0% pre-carriage and on-carriage proportion for rail, road shows a better GHG balance than rail starting from an empty wagon proportion of about 50% (8 empty wagons). When pre-carriage and on-carriage are included, the break-even point is reached with an even lower proportion of empty wagons. With a proportion of 10% pre- and on carriage of the main carriage distance, rail shows slightly higher GHG emissions than road even without empty wagons.

**Conclusion:**
- The number of wagons, pre-carriage and on-carriage distances are decisive factors in the comparison of modes of transport.
- Starting from an empty wagon proportion of about 50% (8 wagons), road performs better than rail for a train with 16 fully loaded wagons.

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38 Based on the average train of the Kombiverkehr corporation (16 wagons with two TEU of 9.1 tonne each).
5.2.4 Generalisations on the container transport of heavy goods

In order to complete the subject of container transport of heavy piece goods, a general comparison will now be drawn.

As this is not a case-specific transport relation, the emissions for the overall comparison of the modes of transport will be related to one tonne-kilometre (tkm).

The following assumptions have been made for the calculation.

- General assumptions:
  - containers are fully loaded in terms of weight, with an overall weight of 26 t

- Specific assumptions for modes of transport:
  - road transport: empty triprate of 10%, according to BGL\textsuperscript{39}
  - truck fuel consumption: 30 l/100 km
  - rail transport: capacity utilisation rate of 100% and empty trip rate of 80%, according to EcoTransIT\textsuperscript{40}
  - In terms of train length/weight, two cases will be considered:
    - a) block train of 500 gross tonnes, with 20 wagons
    - b) block train of 1000 gross tonnes, with 40 wagons

Figure 5-6 is a graphical comparison of the GHG emissions from the selected modes of transport per tkm.

![Figure 5-6: Comparison of GHG emissions during container transport of heavy goods](image)

A train of 500 gross tonnes can be considered, in a first approximation, as representative of the national combined transport. As per own calculations based on the transport


\textsuperscript{40} EcoTransIT: Tool for quantification of emissions from freight transport. Developed by the Institute for Energy and Environmental Research (ifeu), Heidelberg, and Rail Management Consultants GmbH (RMCon), Hannover, 2008-. Available from: <http://www.ecotransit.org/>.
performance of combined transport in 2008\(^{41}\), the average train weight lies at about 560 gross tonnes. The results show that a truck performs better in comparison with an average domestic container train.

A train of 1000 gross tonnes can be considered, in a first approximation, as representative for the international combined transport. As per own calculations based on the transport performance in international combined transport\(^{42}\), the average train weight lies at about 930 gross tonnes. The comparison between truck and a train of 1000 gross tonnes shows that rail and road are approximately on a par.

### Conclusion:
- With respect to short trains (~500 gross tonnes, comparable), comparable to the “average” train operated in national combined transport, road performs better than rail.
- With respect to longer trains (~1000 gross tonnes), rail and road are approximately on a par.

5.3 Transport of light goods

5.3.1 Transport of insulating material (volume-restricted goods)
The comparison of GHG emissions from the transport of light, volume-restricted goods will be illustrated and discussed by the following example.

Transport task: transport of 240 t of insulating material (bulk density 0.08 t/m\(^3\)) from Stuttgart to Rotterdam.

The following assumptions have been made for the calculation.

- General assumptions:
  - no consideration of empty trips
  - 100% volume capacity utilisation per mode of transport

- Specific assumptions for modes of transport:
  - **road transport:** 32% capacity utilisation by mass; semi-trailer for high-volume goods (95 m\(^3\)); distance: 619 km.
  - **rail transport:** 41.6% capacity utilisation by mass; type of wagon: Hbbills 311 freight wagon with 140 m\(^3\); train with 19 wagons; distance: 700 km.


Intermodal comparison

- inland water transport: 8%\(^{43}\) capacity utilisation by mass; vessel type: large motor vessel; distance: 785 km.

Reference unit: as the distances to be covered by the modes of transport are different, the overall emissions for the defined transport case will be indicated in the intermodal comparison.

Figure 5-7 illustrates the GHG emissions from the selected modes of transport for the analysed transport task.

![Figure 5-7: GHG emissions from the transport of insulating material from Stuttgart to Rotterdam](image)

Due to the selection of an ideal type of wagon, rail shows considerably lower GHG emissions than road and inland waterway (by a factor of two). The latter two are on a par.

The influence of the selected type of wagon on the GHG balance will be analysed in the next section.

**Conclusion:**

- In terms of high-volume goods, road is competitive with waterway.
- Further potential for a truck with 25.25 m (40t GVWR).

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\(^{43}\) This low capacity utilisation by mass is due to the transport of insulating material in 40 ft containers on the Neckar (draught and air-draught restrictions) and Rhine rivers. A capacity utilisation by volume is assumed, which means that all container slots on the vessel are occupied. With this assumption the comparison between the individual modes of transport can be done for consistent loads.
5.3.2 Sensitivity analysis: influence of wagon type and train length

In this section, the influence of wagon type and train length on the comparison of rail and road will be analysed.

Transport task: transport of insulating material with a bulk density of 0.08 t/m³.

The following assumptions have been made for the calculation.

- General assumptions:
  - 100% volume capacity utilisation for all modes of transport.
  - no empty runs are assumed for any of the considered modes of transport

- Specific assumptions for modes of transport:
  - road transport: there are two different truck types:
    - a) articulated truck with semitrailer for high-volume goods; load volume: 95 m³
    - b) truck with a 40 ft high cube container; load volume: 76,3 m³
  - rail transport: there are three different wagon types:
    - a) sliding door wagon Hbbills 311; load volume: 140 m³, capacity utilisation by mass for the estimated bulk density: 42%; for orientation purposes: a train weight of about 500 gross tonnes corresponds to 17 wagons.
    - b) container wagon Lgs 580 with a 40 ft high cube maritime container; load volume: 76.3 m³, capacity utilisation by mass for the estimated bulk density: 28%; for orientation purposes: a train weight of about 500 gross tonnes corresponds to 27 wagons.
    - c) hopper wagon Tagos 896; load volume: 75 m³, capacity utilisation by mass for the estimated bulk density: 9%; for orientation purposes: a train weight of about 500 gross tonnes corresponds to 17 wagons.

Reference value: as this is not a case-specific transport relation, the emissions for the overall comparison of transport modes will be related to one tonne-kilometre (tkm).

Figure 5-8 illustrates the GHG emissions from the selected modes of transport in relation to train length (number of wagons: 5/10/15/20) and type of wagon.
Figure 5-8: GHG emissions from the transport of light goods in relation to train length and type of wagon

It shows that a sliding door wagon is the best choice for the transport of light, high-volume goods. However, a truck (semi-trailer for high-volume goods) is on a par with a short train with 6 wagons. When containers are used, the truck (semi-trailer for high-volume goods) is on a par with a train with about 15 wagons. Compared with short trains, the truck shows lower GHG emissions. For transport in hopper wagons, the truck (semi-trailer for high-volume goods) performs even better than a train with 20 wagons.

**Conclusion:**

- Road transport: CO\textsubscript{2}e emissions go up to approximately 100g/tkm for high-volume goods.
- In relation to the type of wagon, road and rail perform comparably for a train length of 5 to 15 wagons (compared with about 20 wagons for heavy goods).
6 Future developments

In this chapter, foreseeable potential changes relative to the individual modes of transport and their impact on an ecological comparison will be analysed. The focus will be on the following topics:

- changes in the German rail power mix
- potential increase in biofuel blending to diesel fuel
- introduction of the EuroCombi
- implementation of future exhaust emission standards (Euro VI)

6.1 Development in the rail power mix and impacts on GHG emissions

The assessment on the development of the future German rail power mix is based on a study\(^44\) commissioned by the BMU. In this study, development of electricity generation is analysed against a background of the withdrawal from the nuclear energy programme and the expansion of renewable energy production in order to achieve the current German climate protection targets. In 2005, the share of nuclear energy in the German rail power mix was 27\(^{45}\) and is therefore comparable to its share in the German grid mix (26\(^{46}\)). Much the same applies to the share of renewable energy, which is 11\% of the German rail power mix and 10\% of the German grid mix. Figure 6-1 shows the fuel mix compositions by energy carrier.

![Figure 6-1: Composition of the German rail power mix compared with several fuel mix scenarios from the BMU pilot study](image)

Based on the development of the German grid mix from 2006 to 2020, as projected in the BMU study (on the premise of the withdrawal from the nuclear energy programme decided...
on in 2002, see Figure 6-1), it may be assumed that in the German rail power mix the share of nuclear energy will decrease (to approximately 6% in 2020, as per BMU study) and the share of renewable energy will increase. According to the lead scenario 2008, in 2020 a share of 30% of renewable energy is expected. In this study, the development of the future German rail power mix and the resulting consequences for the comparison with road transport is considered on the basis of the following two extreme scenarios from the BMU study:

- scenario E3 (higher energy efficiency, major expansion of renewable energy (RE) to a share of 36%, nuclear energy 6%, coal 35%, remainder: natural gas/fuel oil)
- scenario D2 (increased use of coal (49% share), 28% RE, nuclear unchanged at 6%)

Figure 6-2 shows the results for the as-is state (German rail power mix and German grid mix for 2006, according to BMU), the BMU lead scenario for 2020, and the two extreme scenarios.

Figure 6-2: Greenhouse gas emissions from electricity supply for the as-is state and for future development scenarios

Fuel mix 2020 of the lead scenario shows a decrease of -3% in GHG emissions compared with the fuel mix for 2006. Fuel mix 2020 of the extreme scenarios shows a decrease of -10% (E3) and an increase of +6% (D2), respectively.

In its climate protection strategy 2020\(^{47}\), DB AG has set itself the target of reducing the company’s GHG emissions by 20% compared with the reference year 2006. Raising the share of renewable energy is one element in the package of measures to be adopted by DB AG, but further clarification as to how this rise in the share is to come about is required.

**Conclusion:**

- Future development: GHG emissions from the future German rail power mix will remain approximately constant.

6.2 Future developments for road and rail in heavy goods transport

The comparison of future GHG emissions from heavy goods transport by rail and road will be illustrated and discussed based on the following example:

Transport task: transport of swap bodies.

Reference value: as this is not a case-specific transport relation, the emissions for the overall comparison of modes of transport will be related to one tonne-kilometre (tkm).

The following assumptions have been made for the calculation.

- General assumptions:
  - swap body transport
  - no consideration of pre- and on-carriage

- Specific assumptions for modes of transport:
  - road transport: capacity utilisation rate of 100% and empty trip rate of 80%; fuel consumption: 30 l/100 km. In terms of fuel supply, two cases will be considered:
    - a) diesel fuel with a 6.25% blend of NExBTL (business-as-usual scenario)
    - b) diesel fuel with a 20% blend of NExBTL
  - rail transport: capacity utilisation rate of 100% and empty trip rate of 80%, change in fuel mix:
    - a) today's mix\textsuperscript{48}
    - b) best-case scenario (E3)\textsuperscript{49}
    - c) worst-case scenario (D2)

Figure 6-3 and Figure 6-4 show a graphical comparison of the GHG emissions from the selected modes of transport per tkm.


\textsuperscript{49} According to the BMU pilot study, Nitsch 2008.
Future developments

In all future scenarios on container transport, GHG values from road transport are lower than the values from a train of 500 gross tonnes (average for national combined transport: 560 gross tonnes). A potential increase in the share of biofuels would increase the gap between rail and road transport even further.

When compared with a train of 1000 gross tonnes (Figure 6-4), road transport is approximately on a par with rail.

**Conclusion:**
- Even assuming an improvement in the future German rail power mix, road transport is an alternative to rail transport for heavy good transport in containers.
6.3 Future developments for road and rail in the transport of light goods

The comparison of future GHG emissions from the transport of light goods by rail and road will be illustrated and discussed based on the following example:

Transport task: freight of 120 kg/m³, e.g. refrigerators.

In this comparison, special emphasis is put on the so-called EuroCombi currently tested by selected freight forwarding companies. Optimum capacity utilisation (capacity utilisation rate by volume and mass: 100%) of the EuroCombi is achieved by a freight density of approximately 120 kg/m³ (e.g. refrigerators). With a freight density > 120 kg/m³ an optimum volume utilisation is not possible.

Reference value: as this is not a case-specific transport relation, the emissions for the overall comparison of modes of transport will be related to one tonne-kilometre (tkm).

The following assumptions have been made for the calculation.

- General assumptions:
  - no consideration of empty trips

- Specific assumptions for modes of transport:
  - road transport: there are three different cases:
    - conventional truck; diesel fuel with a 7% blend of NExBTL
    - EuroCombi; length of 25.25 metres and maximum volume of 150 m³.
    - EuroCombi; diesel fuel with a 20% blend of NExBTL
  - rail transport: two scenarios will be considered:
    - German rail power mix 2020: increased use of hard coal (BMU scenario D2); type of wagon: hopper wagon
    - German rail power mix 2020: increased use of renewable energy (BMU scenario E3); type of wagon: sliding door wagon

50 Manufacturer’s data and Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr, 2007: Zwischenbericht des niedersächsischen Pilotprojekts „Giga Liner“. 
Figure 6-5 is a graphical comparison of the GHG emissions from the selected modes of transport.

![Graph showing GHG emissions comparison](image)

**Figure 6-5:** Comparison of future specific GHG emissions from the transport of light goods by rail and road

By introducing the EuroCombi, GHG emissions will be considerably reduced even when conventional fuel is used. By increasing the blend rate with NExBTL from 7% to 20%, GHG emissions will be reduced by approximately 10%.

Thereby road transport will also come much closer to the favourable fuel mix scenario (increased use of renewable energy) for rail transport.

**Conclusion:**

- The emissions from road transport lie within the range of potential CO$_2$e emissions from the considered rail transport scenarios.
- Introducing the EuroCombi and increasing the biofuel share can bring significant improvements for road transport.
6.4 Assessment of regulated emissions based on a transport of insulating material

With the introduction of the Euro VI emission standard\(^{51}\) for heavy-duty vehicles by 31 December, 2012, the emission limits for NO\(_x\) and PM will be reduced by 80% and 50%, respectively compared to the Euro V emission standard of 2008. At present, current measured values for Euro VI concepts are not yet available. But current simulation values\(^{52}\) for an averaged route profile similar to the one in the transport task Stuttgart-Rotterdam can be used.

For inland vessels, EU stage IV\(^{53}\) emission limits will come into force in 2014. This will mean a reduction of NO\(_x/PM\) emissions by 96% and 79%, respectively, compared to the 2006 level (see chapter 4.3).

Figure 6-6 shows that tightening of the emission standards will result in an increasing convergence of the contaminant emission values for the three modes of transport.

Conclusion:

- Values of regulated contaminant emissions from the three transport modes will increasingly converge as a result of the coming into force of Euro VI emission standard for road transport in 2012/13 and EU stage IV limits for inland vessels in 2014.

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\(^{52}\) Provided by the VDA Working Group for Commercial Vehicles

7 Conclusions and Outlook

In this study, greenhouse gas emissions and other relevant emissions from long-distance freight transport on road, railway and inland waterway have been analysed and compared with each other.

The overall objective of this study was to examine the hypothesis deriving from various study results: „In long-distance freight traffic rail is chiefly a better environmental solution than road“.

For this purpose, the following items have been considered:

- validity analysis of recent studies results
- revaluation with current data and specific assumptions (based on logistics and means of transport)
- quantitative assessment of possible future developments for the considered modes of transport

7.1 Validity analysis of recent studies results

By an analysis of recent studies it has been shown that publicly discussed comparisons (especially from EcoTransIT) are based on a series of assumptions about road transport that have to be considered no longer relevant. These are, in particular:

- considerably higher consumption values for road transport (30 - 50% higher than recent data from truck manufacturers and users, and test results from professional journals)
- higher rate of empty trips specified for road transport (60% instead of 10% for bulk goods)

Moreover, designating CO₂ emissions instead of describing greenhouse gases as CO₂e is no longer methodologically tenable. Taking other greenhouse gas emissions, such as methane, into account, leads to an increase of GHG emissions from rail transport. This increase is because methane emissions, with a share of 5%, are a relevant factor in electricity supply in Germany. For a diesel truck, on the other hand, methane emissions play a minor role. This means that focusing merely on CO₂ emissions in a comparison of rail and road transport creates an advantage for rail transport.

Furthermore, in comparative calculations important determining factors are assessed by general assumptions, which in reality are not always appropriate. Those are, among others:

- number of wagons (train length)
- type of wagon used
- length of pre-carriage and on-carriage

It became evident that in recent studies all calculations for rail transport are based on EcoTransIT. At present, EcoTransIT does not provide sufficient flexibility in the selection of wagon type and train length for an individual case study of logistic concepts.
7.2 Revaluation with current data and specific assumptions

By means of revaluations it has been shown that the general statement “rail is in general more environmentally friendly than road” is not tenable as it stands. An individual case study of the transport service is required.

From the results of the comparisons based on updated data and logistically adapted assumptions, the following statements can be derived:

Rail transport tends to be better
- in the transportation of bulk materials, e.g. iron fillings
- in container transport of heavy goods with block trains of more than 20-25 wagons (depending on the empty trips rate)
- in the transport of light, high-volume goods with train lengths of more than 5-15 wagons, depending on the type of wagon; when the 25.25 m truck concept is used, the difference diminishes (for goods with a density of less than 200 kg/m³, e.g. insulating material, white goods)
- With waterway transports, payload limitations due to draught and air-draught restrictions are decisive.

Road and rail transport are approximately on a par
- when trains in the magnitude of the average national combined transport (560 gross tonnes) are used.
- when the proportion of empty wagons for a train (of approximately 1000 gross tonnes) lies at 25-50%

Road transport tends to be better
- when short trains with less than 10 wagons are used for heavy-goods transports due to logistical requirements
- when pre-carriage and on-carriage add up to more than 10% of the main carriage for trains with up to, approximately 15 wagons (block trains, no empty wagons or trips).

7.3 Quantifiable assessment of future scenarios

The main variables in the comparison of road and rail transport in the future are:
- the development of the future German rail power mix
- the use of alternative fuels, e.g. the blending quota for biofuels
- the use of alternative vehicle geometry, e.g. the EuroCombi with a length of 25.25 m

Variability of the fuel mix development has been addressed by means of a scenario consideration. It is shown that the assumption of rising GHG emissions from the future German rail power mix (due to the withdrawal from the nuclear energy programme) is only conditionally tenable. On the other hand, the target reduction in greenhouse gas emis-
sions from rail by 20% until 2020 cannot solely be achieved by means of the expected fuel mix, according to BMU scenarios.

Even assuming an improvement in the future German rail power mix, road is a real alternative to rail in the container transport of heavy goods.

By introducing the EuroCombi and increasing the share of biofuels, a significant improvement of the GHG balance, especially for light goods with a density of less than 200kg/m³, can be expected.

Conclusion:

- The general statement “rail is in general more environmentally friendly than road” is not tenable as it stands.
- An individual case study of the transport service has to be done.
Reference list


DB Schenker 2009 DB Schenker/DB Intermodal: „Im Takt quer durch Europa“, railways, no. 02/09, Mainz, 2009.


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Annex A    Sensitivity analysis

One of the key assumptions in this study is the fuel consumption of the truck, which is directly influencing the GHG emissions of truck transport in a linear manner. Within this study (see section 4.1.1) it is assumed to be 30 l/100 km for a fully loaded Euro V truck (40t) and 30.6 l/100km for a fully loaded Euro VI truck (40t).

In order to check the stability and sensitivity of the conclusions drawn in this study with regard to the assumed fuel consumption, the fuel consumption is increased by 10%; i.e. fuel consumption is 33 l/ 100km and 33.7 l/100 km for fully loaded Euro V and Euro VI trucks respectively.

The influence of the adapted fuel consumption will be presented for the example of container transport of heavy piece goods. The other transport tasks analysed in the study have also been investigated applying the 10% increased fuel consumption. They showed similar implications on the results as presented below for the container transport of heavy piece goods.

The adapted fuel consumption of the truck is applied on the generalised comparison of container transport of heavy piece goods (see section 5.2.4). The other assumptions remain unchanged as described in section 5.2.4. The resulting GHG emissions per ton kilometre are displayed in Figure 7-1.

![Figure 7-1](image)

**Figure 7-1**   Comparison of GHG emissions for container transport of heavy piece goods, truck + 10% fuel consumption

As can be seen truck continues to display advantages compared to short trains, for long trains there are advantages for rail transport.

With regard to future developments the influence of an increased fuel consumption is presented in the following two figures, again looking at the container transport of heavy piece goods. The figures correspond to Figure 6-3 and Figure 6-4. The difference is the 10% increase of fuel consumption for the truck, both for Euro IV using 6.25% share of biofuel (truck 40 t) and Euro VI using a 20% biofuel share (truck 40 t (20% NExBtl)).
In comparison to rail transport - using a train with a gross weight of 500 t - truck still demonstrates a better GHG performance for all scenarios (see Figure 7-2). When considering a train with a gross weight of 1000 t (see Figure 7-3) rail transport now has some clearer advantages compared to the truck transport with a 10% increased fuel consumption.

After applying a 10% increased fuel consumption of the truck it can be seen that the GHG emissions of container transport of heavy piece goods are similar and that the difference between rail and truck are significantly lower as stated in current published transport studies.

**Conclusion:**
Generally it can be found that also with a 10% increase of the fuel consumption for the truck the conclusions of this study retain their overall validity.
Annex B Critical acclaim
(in German language only)
Treibhausgasemissionen
im Güterferntransport

Prüfung in Anlehnung an ISO 14040–44

DEKRA Industrial GmbH
Nachhaltigkeitsmanagement
22/06/2010
**AUSGANGSSITUATION**


Neben den Treibhausgasemissionen findet auch eine Betrachtung von NO\textsubscript{X} und PM statt. Die Bereitstellung der Kraftstoffe/Energieträger – Diesel (B7), konventioneller Diesel, NExBTL (B100), Strom – ist ebenfalls Teil des Betrachtungsumfanges.

### Zielsetzung und Untersuchungsrahmen

**Motivation und Ziel der Studie**

In Europa trägt der Verkehrssektor mit 23% der CO\textsubscript{2}-Emissionen einen erheblichen Teil zu Emissionen von Treibhausgasen bei. Prognosen zu Folge wird der Transportsektor an Relevanz zunehmen. Die Verlagerung des Verkehrs von der Straße auf die Schiene wird aktuell dabei häufig als Strategie zur Reduzierung der CO\textsubscript{2}-bzw. Treibhausgasemissionen in Betracht gezogen.

Anlass dieser Studie ist, dass bisher dem LKW deutlich höhere CO\textsubscript{2}-Emissionen im Vergleich mit Bahn oder Schiff zugeordnet werden. Die vorliegende Studie will daher einen Diskussionsbeitrag liefern, der zu einer Neubewertung des LKW als Alternative im Gütertransport führt.

**Untersuchungsrahmen**

Zeitlich: Die Studie wurde im Zeitraum April 2009 bis Februar 2010 durchgeführt und bezieht sich auf verfügbare Daten für LKW, Schiff und Bahn.

Geografisch: Die Studie bezieht sich auf Deutschland.

Betrachtete Emissionen: Treibhausgase (THG, insbesondere CO\textsubscript{2}, wobei weitere Treibhausgase wie CH\textsubscript{4} und N\textsubscript{2}O als Kohlendioxid-Äquivalente CO\textsubscript{2}e einbezogen werden) sowie NO\textsubscript{x}- und Partikel-Emissionen.

**Bezugsgrößen**

Als Bezugsgrößen der Berechnungen liegen Angaben zu den einzelnen Verkehrsträgern, der Transporteffizienz sowie den spezifischen Transportdienstleistungen zu Grunde.

Für die Verkehrsträger flossen in die Berechnung unter anderem Kraftstoffverbrauch, Fahrprofil bzw. Verkehrssituation sowie Bereitstellung von Kraftstoffs bzw. Strom ein.

In Bezug auf die Transporteffizienz werden Annahmen zur Kapazität und Auslastung der Transportfahrzeuge sowie Transportdistanzen für den Haupt-, Vor- und Nachlauf in beispielhaften Relationen hinzugefügt.

Basierend auf diesen Einflussgrößen wird jeweils die spezifische THG-Emission als gCO\textsubscript{2}e/tkm bzw. kgCO\textsubscript{2}e/Transportaufgabe berechnet.
Systemgrenzen

Die Studie basiert auf einem ganzheitlichen Ansatz. Es werden die Emissionen des Fahrbetriebes selbst sowie die Emissionen zur Bereitstellung der Energieträger bzw. Kraftstoffe berücksichtigt. Die Berechnungsstufen, Bezugsgrößen und wesentlichen Einflussfaktoren sind auf S. 18/19 der Studie dargestellt.

Datenlage

Die Berechnungen wurden in Excel durchgeführt. Einige Primärdaten wurden GaBi 4 entnommen (z.B. Strom- und Dieselvorketten).

Verkehrsträger

- Kraftstoffverbrauch und Emissionen LKW
  Bisher wird für den LKW gemeinhin ein Diesel-Kraftstoffverbrauch von 39-46 L/100km angenommen. Aufgrund derzeit aktuell verfügbarer Daten wird in dieser Studie hingegen ein Verbrauch von 30 L/100km als realistischer angesehen.
  Der Verbrauchswert von 30 L/100km stammt von Fahrzeugherstellern aus Simulationsrechnungen, validiert durch Verbrauchsfahrten durchgeführt von Herstellern und Fachzeitschriften. Für den Euro VI-Standard nimmt der VDA einen Mehrverbrauch von 2% an.
  Davon ausgehend werden die direkten CO\textsubscript{2}-Emissionen bezogen auf die Fahrleistung berechnet. Die Daten für NOx und Partikelemissionen sind Angaben des VDA.

- Kraftstoffverbrauch und Emissionen Binnenschiff
  Emissionswerte für die Zukunftsszenarien entsprechend der EG Stufe IV für Binnenschiffe beruhend auf den Angaben der Richtlinie 2004/26/EG.

- Energieverbrauch Güterzug
  Die Werte für den Energieverbrauch wurden dem Transportinformationstool EcoTransIT entnommen. Die Dokumentation deutet darauf hin, dass die Daten von Anfang der 90er Jahre stammen.
Energieträger

Vorkettendaten zur Bereitstellung von Diesel für die Verkehrsträger stammen aus der Datenbank GaBi 4 (Bezugsjahr 2006). Das gilt ebenfalls für den Ansatz einer Beimischung von Biodiesel (6,25% bzw. 20% energiebezogen).


Berechnungsmethode

Vorgehensweise

Die Grunddaten für die einzelnen Verkehrsträger (Transportleistung und spezifischer Kraftstoff- bzw. Stromverbrauch) wurden umgerechnet in Emissionen bezogen auf die ausgewählten beispielhaften Fahrspiele. Dabei wurden weitere Parameter (Transporteffizienz und Logistik-Randbedingungen) festgelegt.


Symmetrie der Daten

Die Studie beruht gemäß Darlegung auf den derzeit bestverfügbaren Daten. Es wäre wünschenswert das bei EcoTransIT eine bessere Möglichkeit zur Differenzierung der logistischen Randbedingungen zur Unterstützung von Szenarioanalysen bestünde.

- LKW: Euro V bzw. Euro VI (Zukunftsszenario);
- Bahn: Verbrauchswerte aus EcoTransIT, Daten zur Strombereitstellung von 2005;
- Schiff: aktuelle Daten und Stand der Technik (Zukunftsszenario).

Anmerkung: Zur Abschätzung der Einflussgröße Stromverbrauch Bahn auf die Ergebnisse wäre ein Szenario für diesen Parameter zu empfehlen.


Szenarien bzw. Fahrspiele

Sensitivitätsanalysen bezüglich dem Tarnsport von schweren und leichten Gütern wurden für folgende Parameter durchgeführt:

- Transport schweres Stückgut in Containern – Einfluss von Vor- und Nachlauf sowie Leerwagenanteil und Zuglänge (zwei Analysen);

Weitere Annahmen


Plausibilitätsprüfung

Direkte und indirekte Emissionen

**LKW direkte Emissionen**
Euro V LKW 40 t vollbeladen
800 gCO\(_2\)/Fzgkm ~ 30 l/100 km * 2,665 CO\(_2\)/lDiesel → OK

Euro V LKW 40 t vollbeladen
816 gCO\(_2\)/Fzgkm ~ (30 l/100 km * 2,665 CO\(_2\)/lDiesel) + 2 % → OK

**LKW Gesamtemissionen**
Für die Gesamtemissionen liegen die direkten Emissionen in der Nutzung bei 0,75 kgCO\(_2\)/Fzgkm und die indirekten zur Dieselbereitstellung bei 0,12 kgCO\(_2\)/Fzgkm.

0,75 kgCO\(_2\)/Fzgkm ~ 0,8 kgCO\(_2\)/Fzgkm – 6% → OK

0,12 kgCO\(_2\)/Fzgkm ~ 0,41 kg CO\(_2\)/lDiesel * 0,3 lDiesel/Fzgkm → OK

**Güterzüge**

Für die Bereitstellung des Bahnstroms wird ein Wert von 641 gCO\(_2\)/kWh angenommen. Dieser Faktor liegt über dem angegebenen Wert der deutschen Bahn mit 592 gCO\(_2\)/kWh. Diese Erhöhung ergibt sich durch die Ergänzung durch das THG Gas CH\(_4\).

641 gCO\(_2\)/kWh ~ 592 gCO\(_2\)/kWh + 42,6 CO\(_2\)/lDiesel → OK

**Binnenschiff (indirekte und direkte Emissionen)**
Der spezifische Kraftstoffverbrauch wird in dieser Studie mit 200 g/kWh angenommen. Mit diesem Wert wird der Kraftstoffverbrauch (kg/h) errechnet, der den Rückschluss auf direkte Emissionen zulässt. Sie wurden auf 630 gCO\(_2\)/kWh nach PLANCO 2007 berechnet.
Fahrspiel schwere Stückgüter – Fall 2

Zug
1,4 tCO₂e/Fahrspiel ~ 89,95 Wh/tkm * (113 t*2) * 108 km * 0,641 kgCO₂e/kWh \(\rightarrow\) OK

LKW
1,1 tCO₂e/Fahrspiel ~ 12*0,28 l/Fzgkm * (2,665*0,9375 + 0,41 kg CO2/l Diesel) * 115
\(\rightarrow\) OK

Fahrspiel leichte Güter

Zug
7 tCO₂e/Fahrspiel ~ 72,4 Wh/tkm * 225 t * 700 km * 0,641 kgCO₂e/kWh \(\rightarrow\) OK

LKW
13 tCO₂e/Fahrspiel ~ 30 LKW * 800 gCO₂ * 619 km \(\rightarrow\) OK

Schiff
14 tCO₂e/Fahrspiel ~ [(47,5 l/h * 200/18 km/h + 155,8 l/h * 578/25,8 km/h) + 0,42 kgCO₂e/kgDiesel] * 3,175 kgCO₂e/kgDiesel \(\rightarrow\) OK

**Ergebnisse und Interpretation**

Die Schlussfolgerungen der Studie stützen sich angemessen auf die vorgelegten Berechnungen und Ergebnisse.

So wird insbesondere offenkundig, dass die bisherigen Ansätze zum durchschnittlichen Kraftstoffverbrauch des LKW zu einer deutlich zu nachteiligen Bewertung führen, während aktuell als repräsentativ angesehene Werte eine ökologische Wettbewerbsfähigkeit durchaus erwarten lassen.


Die Autoren der Studie verknüpfen die Schlussfolgerung, dass eine verallgemeinerte Aussage zur generellen Bevorzugung eines Verkehrsträgers nicht möglich erscheint, mit einem Dialogangebot.
Kritische Würdigung


Neben den Treibhausgasemissionen findet auch eine Betrachtung von NO\textsubscript{X} und PM statt. Die Bereitstellung von Kraftstoffe/Energieträger – Dieselkraftstoffe, Strom – ist ebenfalls Teil des Betrachtungsumfanges.

Die errechneten Werte wurden von unabhängigen Dritten auf Zielsetzung und Untersuchungsrahmen, Datenlage und Berechnungsmethodik geprüft und lassen folgende Würdigung der Studie zu:

- Die Datenlage ist für die Zwecke der Studie angemessen und hinreichend aktuell. Die Daten für LKW und Schiff stammen aus aktuellen unabhängigen Quellen. Die Daten für die Bahn hingegen bedürfen einer Differenzierung in Bezug auf logistische Randbedingungen.
- Die Schlussfolgerungen stützen sich auf die ermittelten Ergebnisse und sind angemessen formuliert.

ANHANG

Das Punktschema zur Prüfung

- **Kritischer Punkt** – Zwingend notwendig, um die Konformität mit der ISO zu erreichen, oder um nicht den Erfolg der Studie zu beeinträchtigen
- **Optionale Verbesserung** – Sollte in Betracht gezogen werden, um formale Aspekte der ISO-konformen Berichterstattung zu erfüllen und die kritische Überprüfung zu erleichtern oder zu verbessern.
- **Bestanden** – die Konformität mit der ISO liegt vor
- **Ausschluss** - Punkt nicht in den Anwendungsbereich der ISO