LIFE CYCLE ASSESSMENT
OF
MEANS OF TRANSPORT
FOR
GOODS TRAFFIC

Term paper within the lecture “915.344 Technology Assessment”

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1. Contents

2. Executive summary

In the present term paper LCA-results of means of transport in goods traffic are interpreted. The study concentrates on quantitatively and economically relevant modes of transport, i.e. lorry, train and ship. Both, results from life cycle inventory (LCI) and from life cycle impact assessment (LCIA) are used.

Two sources for LCI and LCIA data were consulted:

1. Handbook Emission Factors For Road Transport [HBEFA V2.1 2004]
   The "Handbook" delivers LCI data for the operation phase of road traffic. From the emission factors provided by "Handbook" fuel consumption, CO_2-, NO_X-, PM- and VOC-emissions were selected.
2. Implementation of Life Cycle Impact Assessment Methods [ecoinvent 2004]
   "ecoinvent" delivers LCI and LCIA data for different means of transport over the whole life cycle. The indicators selected are: abiotic resources, global warming, stratospheric ozone depletion, fresh water aquatic ecotoxicological impact, marine aquatic ecotoxicological impact, testrial ecotoxicological impact, hutoxicological impact, pochemical oxidant formation, aidification, eutrophication, primary energy content of non-renewable resources, primary energy content of renewable resources, primary energy content (total).

No normalisation, weighting or aggregation was performed. Sensitivity analysis and statistical methods also had to be abondonded within the frame of the study. So interpretation was carried out descriptively by collating the data into graphs and tables and discussing them.

The main results for the road transport based on the "Handbook" are:

- The PM-, VOC- and NOX-emissions from Euro 4 vehicles are considerably lower than those from older vehicle models. On the contrary the CO_2-emissions and the fuel consumption have not improved notably since the 1980s.
- Because of their high net weight heavy lorries show relatively high emission factors if they are driven empty. Therefore a high capacity utilisation is even more important for heavy lorries. Related to the provided benefit heavier lorries perform better than light lorries because of their higher loading capacity.
- In extra urban conditions the emission factors are not very sensitive to the velocity as long as the traffic is fluid, but they are considerably influenced by stop-and-go-situations (holdups on highways ("AB-Stop+Go") and urban side roads ("IO_LS")
- The emission factors seem to be more sensitive to the incline than to any other of the considered parameters and raise with increasing incline. This fact should be looked at distinctly in mountained regions.

The LCIA data derived from "ecoinvent" lead to the following conclusions:

- The operation phase contributes at least 50 percent to the environmental impacts over the whole life cycle of the means of transport. Only the toxicity indicators are also significantly influenced by the environmental impacts of the manufacturing processes.
- In the comparison of trains operating with Austrian electricity mix, European electricity mix and diesel, the trains operating with diesel cause by far the highest environmental impacts except in the toxicity indcators and in the use of renewable primary energy, where the trains operating with European electricity mix display the worst performance. Austrian electricity mix is the most environmentally friendly energy source for trains.

- While most of the environmental indicators remain more or less the same, the photochemical oxidation potential (POCP), acidifiation potential (AP) and nutrification potential (NP) (all dependent on VOC and NO_X emissions) diminish significantly from class Euro 3 to Euro 4.
- Road traffic causes the highest environmental impacts in all considered impact categories. The best environmental profile goes either to the rail transport or to the ocean transport depending on the regarded impact category. Compared to inland navigation the rail transport in Austria benefits from the relative high amount of renewable energy in the Austrian energy mix.

The results of the term paper could be the basis for further work in technology assessment of transportation systems by providing information about LCI and LCIA results.

3. Abbrevation and terms

Abiot	Abiotic resources (kg Sb eq)
AP	Acidification (kg SO_2 eq)
CO	carbon monoxide
ecoinvent	LCA data base [ecoinvent 2004]
FWtox	Fresh water aquatic ecotoxicology (kg 1,4-DB eq)
GWP	Global warming potential (kg CO_2 eq)
Handbook	Handbook Emission Factors for Road Transport [HBEFA V2.1, 2004]
Htox	Human toxicological impacts (kg 1,4-DB eq)
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MarTox	Marine aquatic ecotoxicology (kg 1,4-DB eq)
NO_X	nitrogen oxides
NP	Eutrophication (kg PO_4^{3-} eq)
ODP	Stratospheric ozone depletion potential (kg CFC-11 eq)
PEC n.ren.	Primary energy content of non-renewable resources (MJ)
PEC ren	Primary energy content of renewable resources (MJ)
PEC total	Primary energy content (total) (MJ)
PM	Particulate matter
PM_{10}	Particulate matter with aerodynamic diameter < 10 µm
POCP	Photochemical oxidant formation (kg C_2H_4 eq)
TerTox	Terrestrial ecotoxicology (kg 1,4-DB eq)
VOC	Volatile organic compounds

4. Objective

The direct objective of the study is to get a feeling for the life cycle assessment (LCA) methodology thaught in the lecture “technology assessment” and to gather experience with the interpretation of LCA results. The objects of investigation are means of transport in goods traffic. The topic was chosen because goods traffic is one of the most relevant environmental factor in Austria. This predication can be backed up with some statements from the VCOE-leaflet “Efficienter Güterverkehr – Profit für Wirtschaft und Umwelt” [Rauh 2005]

- Since 1970 the freight transport volume, i.e. the amount of transported goods, increased by more than 20 percent. In the same time the transportation sevice (“Transportleistung”), i.e. the product of volume and distance, doubled.
- From 1990 to 2002 the transportations service increased faster than the economic growth (34 % compared to 27 %), which means that the goods traffic cover a lengthening distance.
- Traffic features the largest growth of green house gas emissions of all economic sectors.
- The air pollution with nitrogen oxides and particulate matter remains above the permitted limit values in urban regions and narrow valleys in spite of technical improvements.
- A growing number of citizens is set out increasing noise exposure.
- The transportation infrastructure approaches unceasingly its capacity limits.

The study at hand could be the basis for further work in technology assessment of transportation systems by providing information about LCI and LCIA results. It of course has to make strict boundaries within the scope of the term work since comprehensive assessment of transportation systems is a branch of study on its own. So the present term paper is restricted to the quantitatively and economically relevant modes of transport in goods traffic, i.e. road, rail and water. Only the single use of means of transport is investigated (no combined traffic). It is also not an aim to investigate different telematic or distribution logistics (e.g. distribution via freight village) or the influence of political measurements.

5. Methodology

5.1 General approach

The methodology used is the life cycle assessment (LCA) as already stated in the title. LCA is standardised in ÖNORM EN ISO 14040 ff and more in detail in “Life Cycle assessment: An operational guide to the ISO standards” [CML 2001]. The four steps of LCA are goal definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation. Both, results from LCI and from LCIA are used within the term paper at hand. No normalisation, weighting or aggregation is performed. Sensitivity analysis and statistical methods had to be abondonded too. So interpretation is carried out descriptively by collating the data into graphs and tables and discussing them.
In the scope of the term work it was not possible to make an own life cycle inventory of means of transport. So in the beginning of the study a literature research among the stock of the TU- and BOKU-library was carried out in order to find existing data resulting from life cycle assessments of transport systems. Two main data sources have been identified:

- Handbook Emission Factors For Road Transport, HBEFA V2.1, Februar 2004. PC tool on CD-ROM- BOKU-Bibl.N° 63.52 BEL (E231 Institut für Verkehrsplanung und Verkehrstechnik) (referred to as “Handbook” within this study)
- ecoinvent 2004. Implementation of Life Cycle Impact Assessment Methods, Data v1.1, Dübendorf, May 2004 (referred to as “ecoinvent”). The data are created with the help of the tool SimaPro 7.1.

The “Handbook” delivers LCI for road transport, “ecoinvent” LCI and LCIA data for different transportation means. Although it would be interesting to compare the LCI data for the two sources or to try to make an impact assessment of the available LCI data of the “Handbook” this was not possible within the scope of the term paper. So the two sources were regarded and interpreted separately with the following objectives:

- Investigation of significant environmental parameters of the operation phase to different means of road transport based on LCI data from “Handbook”.
- Investigation of the potential environmental impacts of different means of transport based on the LCIA data from “ecoinvent”.

5.2 Methodology of the basic studies

5.2.1 Handbook Emission Factors For Road Transport

The “Handbook” [HBEFA V2.1, 2004] provides

- Vehicle-specific emission factors (in g/km) in different traffic situations
- data of stock and kilometrage for the different vehicle categories

It delivers data for the countries Austria, Germany and Switzerland (only the Austrian data are used within the term paper). The database allows interrogations about average emission factors whereby the vehicle-specific emission factors are weighted by their relative kilometrage share. For every lorry category the database also includes the kilometrage attributed to the road category. They account for the different kilometrage of lorries according to their particular magnitude. For example heavy lorries drive approximatlely 70 % of their kilometrage on highways and speedways, smaller lorries only 47 %. The parameters (data source in brackets) considered are

- gasoline/diesel consumption (substantiated measurements)
- CO, VOC, NO_x, PM, CO_2 (substantiated measurements)
- Pb, SO_2, CH_4, NMVOC (non-methane VOC), benzol, toluol, xylol (additional measurements and/or literatur research)
- N_2O, NH_3 (indicative reference)

The methodology underlying the manual and the associated software package for the Austrian traffic situation (GLOBEMI) is explained explicitly in [INFRAS 2004] and [Hausberger 2003].

5.2.2 ecoinvent

The ecoinvent data v2.0 comprises unified and generic LCI data of high quality covering energy, transport, building materials, wood, renewable fibres, metals, chemicals, electronics, mechanical engineering, paper and pulp, plastics, waste treatment and agricultural products.

The analysed means of transport mainly rely on the market situation in Europe (RER) and Switzerland (CH) in the year 2004/2005.

The processes included in the ecoinvent database represent in most cases the average of currently used technology. The methodology is described in detail in [Frischknecht 2007].

As stated in [Frischknecht 2007] “the LCI and LCIA results of ecoinvent datasets should not directly be compared with the aim to identify environmentally preferable products or services. For comparative assessments, problem- and case-specific particularities need to be taken into account, if relevant.” This is nevertheless done in the present term paper and shall be appologized by the base experimental research level of the term paper.

6. Investigation model

6.1 Means of transport

The transportation volume in Austria accounted for 472 Mio tons in 1999. This volume splitted into the different mode of transports is shown in Table 1:

mode of transports	freight transport volume	percentage	average transp. distance
road	331 Mio tons	app. 70 %	77 km
rail	74 Miot tons	app. 16 %	204 km
pipeline	57 Mio tons	app. 12 %	244 km
water	10 Mio tons	app. 2 %	223 km
air freight	-	<< 1 %	-

Table 1: transportation volume of different mode of transports in Austria in 1999 (Source: Umweltbundesamt, homepage, 26.12.2008)

The study concentrates on quantitatively and economically relevant modes of transport. So air freight is neglected because of the small amount and moreover the lacking potential for prospective sustainable goods traffic. Innovative means of transport in goods traffic as tram or metro in urban areas, cable cars, lorries with gas fuel, hybride or solar drive are also not considered.
Pipelines are used as supply lines for drinking and processing water, for distance heating, for the transportation of primary energy carriers as oil, gas and coal or for the transportation of refinary products and raw materials (ore). But since they distinguish so fundamentally to the other modes of transport (the freight itself moves, not the means of transport) it was excluded from the present study.

Thus the remaining means of transport are lorry, train and ship.

6.1.1 Lorries

The selected lorries from “Handbook” are:

- heavy lorries >34-40t (36 % of total kilometrage)
- lorries <28t (17 % of total kilometrage)
- light lorries <7,5t (28 % of total kilometrage)
- average lorry according to “Handbook”

The background of the selection is to cover a high amount (83 %) and a broad spectrum of lorries in use in Austria.

CO, NO_X, VOC and PM emissions are particularly relevant environmental parameters caused by road traffic. Since 1993 these emissions are regulated by European law for new heavy-duty diesel engines (Directive 88/77/EEC, followed by a number of amendments). These European emission regulations are commonly referred to as Euro 1 ... 6. In October 2006 the emission class Euro 4 became effective and from September 2009 on, the class Euro 5 will be obliging.
The lorries in the “Handbook” cover 1950s model, 1960s model, 1970s model, 1980s model, Euro 1, Euro 2, Euro 3 and Euro 4. The LCI data of these emission types will be investigated in chapter “7.1.2 Influence on emission type and degree of load”.
Since the environmental profile of the emission classes is already investigated on basis of the “Handbook”, only the actually relevant emission types Euro 3, Euro 4 and Euro 5 are excerpted from “ecoinvent”.

In [OIR 2006] the year of manufacturing and the emission type of vehicles for goods traffic in Austria were analysed based on the data of Statistics Austria for heavy vehicles (lorries > 3,5t and tractor trailer). As can be seen from Table 2 the majority of lorries is younger than 4 years and classified in Euro 3. Therefore in the present study Euro3-class is taken to compare the environmental burdens of road traffic with other modes of transport.

year of manufacture	**emission class**	**Lorry**	**tractor trailer**	**total**	**% lorry**	**% tractor trailor**	**% total.**
vor 1987	Pre-Euro	23.888	217	24.105	7	1,1	6,8
1988-1991	Euro 0	30.805	546	31.351	9	2,7	8,9
1992-1994	Euro 1	37.009	669	37.678	11,1	3,3	10,7
1995-1999	Euro 2	102.046	4.012	106.058	30,6	20,0	30,0
2000-2004	Euro 3	139.228	14.635	153.863	41,8	72,9	43,6
Total		332.976	20.079	353.055	100,0	100,0	100,0

Table 2: Number of lorries and tractor trailers in 2004 according to year of manufacturing and emission class [Source: OIR 2006]

6.1.2 Trains

“ecoinvent” comprises LCIA data for three different types of rail transport relevant for the study at hand:

- rail transport operating with European electricity mix
- rail transport operating with Austrian electricity mix
- rail transport operating with diesel

6.1.3 Ships

In ecoinvent there are two moduls for ship transportation:

- inland navigation transport (“Binnenschifffahrt”)
- ocean transport

6.2 Functional unit

The “Handbook” delivers LCI data related to the transportation distance in km with additional declaration of the loading stage (empty, 50%-loaded, laden). T he LCIA data from “ecoinvent” on the other hand are related to the mass of transported goods (here: 1 ton) multiplied with the transportation distance (1 km).

6.3 System boundaries

Within the scope of the term work the following system boundaries had to be set:

- The work concentrates on Austrian circumstances (Austrian climate, Austrian electricity mix, Austrian LCIA data if available, etc.)
- Following the LCA approach of “ecoinvent”, the geographical system boundary comprises the entire world. No region is excluded in advance.
- The data chosen from the “Handbook” and “ecoinvent” represent the state of transport in the year 2005.
- The regarded life cycle phases are taken over from the underlying basic studies, i.e. operation phase for the “Handbook”-data and whole life cycle for the “ecoinvent”-data.

6.4 Environmental parameters

As already stated the study at hand includes

- LCI results for the operation phase based on “Handbook” and
- LCIA results for the whole life cycle based on “ecoinvent”

LCA methodology is based upon inputs and outputs of processes. For goods traffic the following inputs and outputs could be environmentally relevant:

- energy and raw material consumption (fuel, steel, plastics,…)
- emissions into air (CO_2, CO, NO_x, PM, VOC, …)
- emission into water and soil (NO_X, Pb, …)
- waste

The parameters considered in “Handbook” are: fuel consumption, CO-, VOC-, NO_x-, PM-, CO_2-, Pb-, SO_2-, CH_4-, NMVOC- (non-methane VOC), benzol-, toluol-, xylol-, N_2O-, NH_3-emissions. In order to kepp the effort manageable and the results clear the following LCI parameters were selected from the list above because of their relevance in environmental politics:

- NO_X-emissions,
- PM-emissions,
- CO_2-emissions
- VOC-emissions and
- fuel consumption

In the lecture “technology assessment” a set of impact categories were listed (page 15 of the presentation “Life Cycle Assessment – Introduction”). All listed impact categories could be gathered from “ecoinvent” except depletion of biotic ressources, land use and work environment (no data available). In addition the primary energy consumption (separated into non renewable and renewable energy sources) is quoted in the term paper because of its popularity – although it is not a result from LCIA, but from LCI.

Indicator	**Abbrevation**	**unit**
Abiotic resources	**Abiot**	**kg Sb eq**
Global warming	**GWP**	**kg CO_2 eq**
Stratospheric ozone depletion	ODP	kg CFC-11 eq
Fresh water aquatic ecotoxicological impact	FW Tox	kg 1,4-DB eq
Marine aquatic ecotoxicological impact	MarTox	kg 1,4-DB eq
Terrestrial ecotoxicological impact	TerTox	kg 1,4-DB eq
Human toxicological impact	Htox	kg 1,4-DB eq
Photochemical oxidant formation	**POCP**	kg C_2H_4
Acidification	**AP**	kg SO_2 eq
Eutrophication	**NP**	**kg PO_4^{3-} eq**
Primary energy content of non-renewable resources	PEC n.ren.	MJ
Primary energy content of renewable resources	PEC ren	MJ
Primary energy content (total)	**PEC total**	**MJ**

Table 3: Environmental indicators derived from “ecoinvent”. The indicators are used to investigate the environmental profile of each mode of transport. For comparisons between the different modes only the bold indicators are used.

The listed indicators are used to investigate the environmental profile of each mode of transport.
For the comparison of different modes of transport only the bold indicators are selected. Stratospheric ozone depletion is excluded in this comparison because of its lack of importance since the prohibition of corresponding substances in Austria, the toxicity impacts because of their debatable methodological background.

6.5 Aggregation and evaluation method

see chapter “5.1 General approach”

6.6 Strategy for data collection

see chapter “5.1 General approach”

7. Results

7.1 Results based on “Handbook”

7.1.1 General remarks

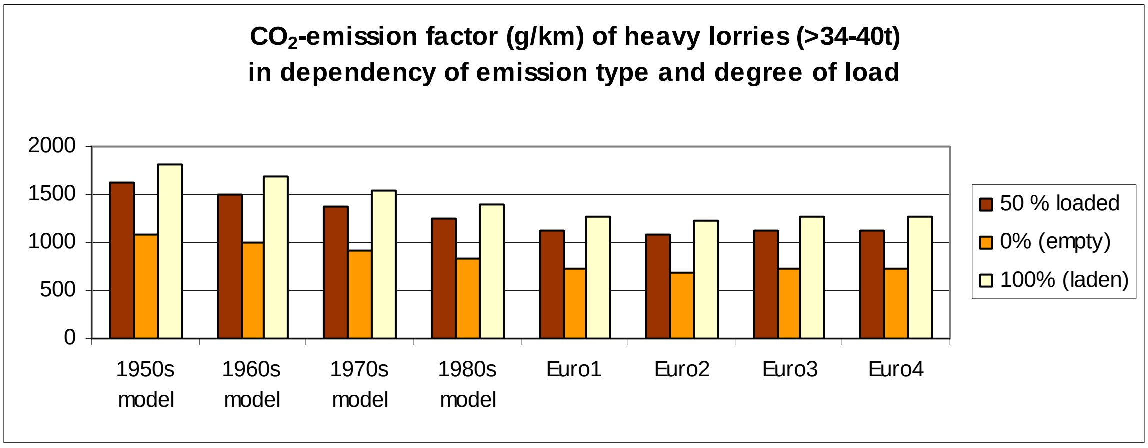
The results form the “Handbook” are gained using the following assumptions:

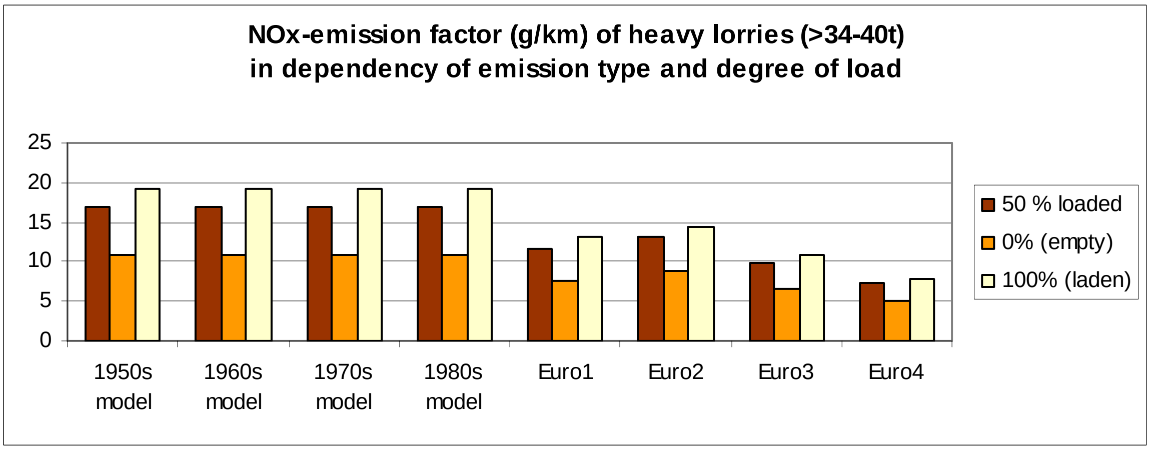
- Since lorries above 3,5 t with gasoline motor have not appeared in the registration approval since 1993 [Hausberger 2003], only diesel vehicles are considered.
- Unless otherwise noted the opted conditions are plane road (0% incline) and average road conditions.
- Due to the limited workscope the term paper restricts to the parameters fuel consumption, CO_2-, NO_x-, PM- and VOC-emissions.

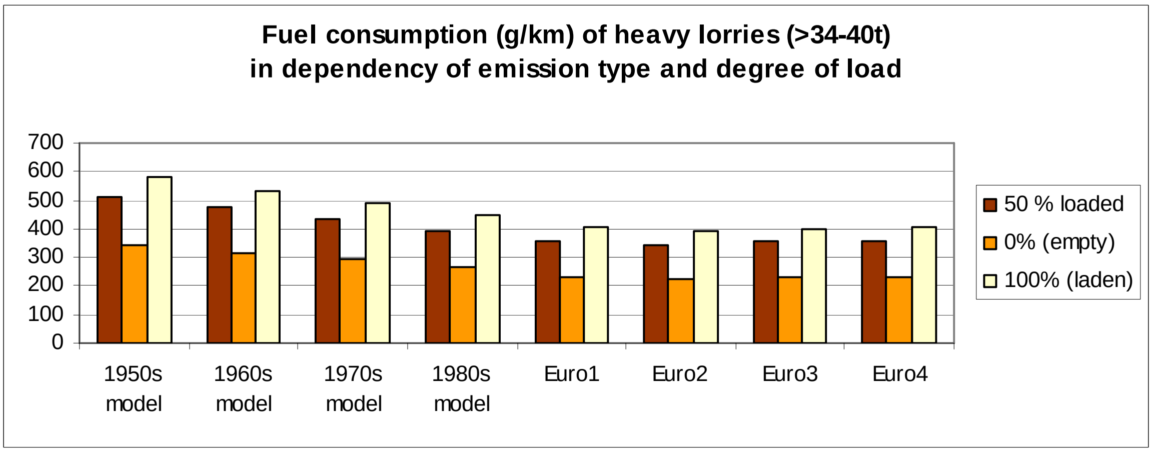
- The emission factors are evaluated for
  – heavy lorries >34-40t (36 % of total kilometrage)
  – lorries <28t (17 % of total kilometrage)
  – light lorries <7,5t (28 % of total kilometrage)
  – average lorry according to “Handbook”
- Note: The “Handbook” covers only the operation phase of road transport.

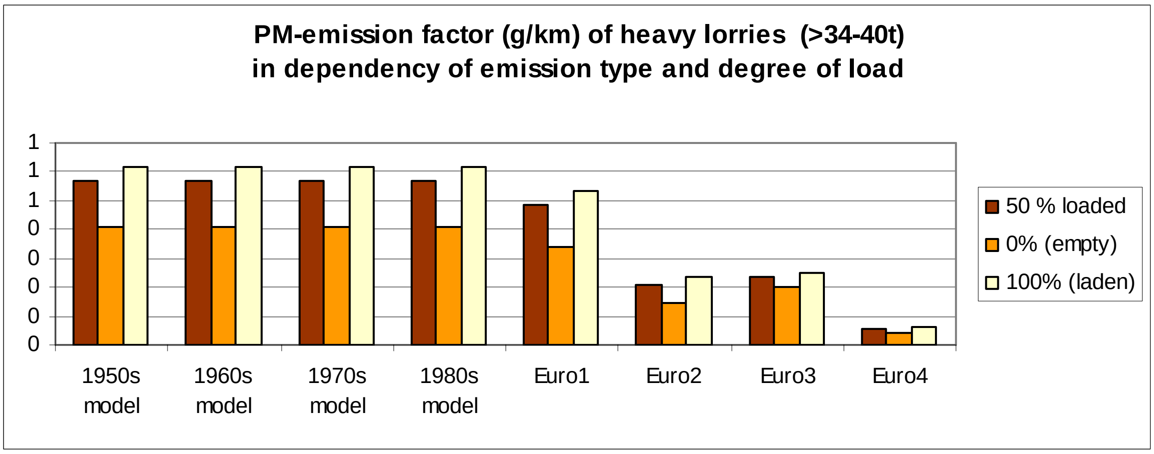
7.1.2 Influence of emission type and degree of load

Figure 1 shows the emission factors of the considered parameters for lorries in dependency of emission type and degree of load.









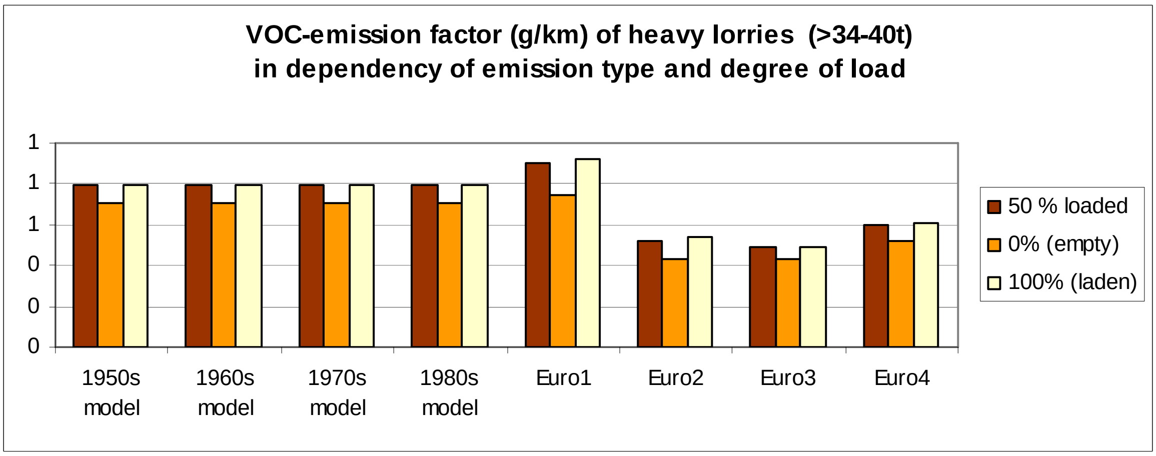


Figure 1: Fuel consumption, CO_2-, PM-, NO_X- and VOC-emission factor (g/km) of heavy lorries (>34-40t) in dependency of emission type and degree of load. The figures for light lorries (<7,5t) and lorries <28t show a similar behavior concerning the development from the 1950s until Euro 4.

As can be seen from the figures the CO_2-emission factor and the fuel consumption hasn't improved significantly since the 1980s (app. 10 %) and only 30 % compared to the 1950s. The PM-emission factor on the contrary has been reduced significantly due to the European regulation and will take another step forward due to the implementation of the Euro 4 class. This is also widely true for the VOC- and NO_X-emission factor. The NO_X-emission factor shows an interesting effect in the transition from Euro 1 to Euro 2: It raises although the limit values are stricter for Euro 2 than for Euro 1. As has been worked out in [INFRAS 2004] this is due to the fact that the new technologies for the low emission classes allow to optimise the motor under various aspects. Since the fuel consumption is a relevant competition factor, the manufacturers try to minimise it as far as possible. So they optimise the NO_X-emission in the compulsary stationay testing method in a way that also the fuel consumption is minimised. But the stationary testing method does not garantuee that the emission level is also diminished considerably in the real driving operation. New testing methods have improved the situation for Euro 3- and Euro 4-motors. The increase of the VOC-emission factor from Euro 3 to Euro 4 standard could not be interpreted within the study.

What we can also learn from the figures above is that the dependency of the emission factor on the degree of load is rather high for the considered heavy lorries. This applies less for lighter lorries as can be seen in Figure 2, where the emission factor of the vehicle types <7,5t, <28t and >34-40t with 0 %

(empty) and 50 % degree of load are compared to laden vehicles (emission factor = 100 %). This is quite clear considering the by far heavier transport weight of heavy vehicles.

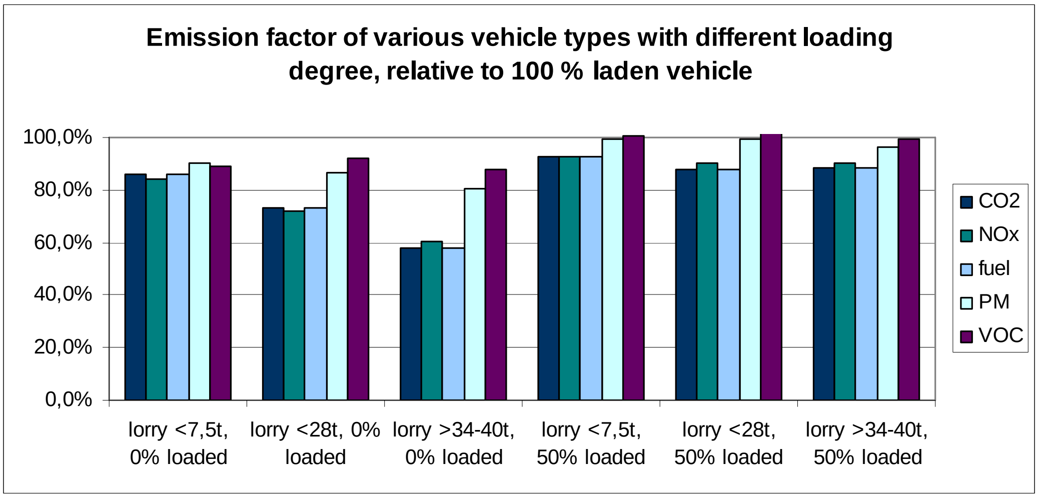
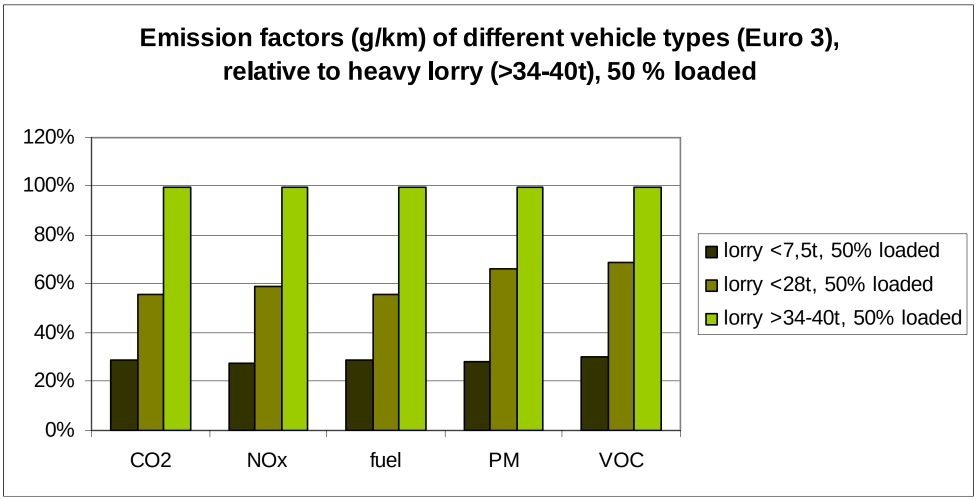


Figure 2: Emission factor of various vehicle types with 0 % (empty) and 50 % degree of load compared to 100 % (laden) vehicles (emission factor = 100%). The heavier the vehicle the higher the relative difference between empty and laden vehicles (except for VOC-emissions).

7.1.3 Influence of the loading capacity

The different environmental performances related to the transport distance of light lorry (<7,5t), lorry <28 t and heavy lorries (<34-40 t) is pictured in Figure 3.



Emission factors in g/km	**CO_2**	**NO_x**	**fuel**	**PM**	**VOC**
lorry < 7,5 t, Euro3, 50% loaded	325,65	2,74	103,38	0,07	0,15
lorry < 28 t, Euro3, 50% loaded	621,74	5,85	197,38	0,16	0,34
lorry > 34-40t, Euro3, 50% loaded	1118,19	9,85	354,98	0,24	0,49

Figure 3: Fuel consumption (“fuel”), CO_2-, NO_X- PM- and VOC-emission factor in g/km for different vehicle types (lorries <7,5 t, <28 t and <34-40 t) relative to heavy lorries (>34-40 t) and absolute values (table). Degree of load: 50 %. The relative difference between the various vehicles is similar with 0% and 100% load factor).

Heavy lorries display higher emission factors per transport distance than light lorries. This result is however misleading since we have to consider the provided benefit (transported good). In order to estimate the benefit the following transported volume was assumed[1]:

freight mass related to degree of load	**100 % loaded**	**50% loaded**
lorries <7,5t	5,6 tons	2,8 tons
lorries <28	21,0 tons	10,5 tons
lorries >34-40t	30,0 tons	15 tons

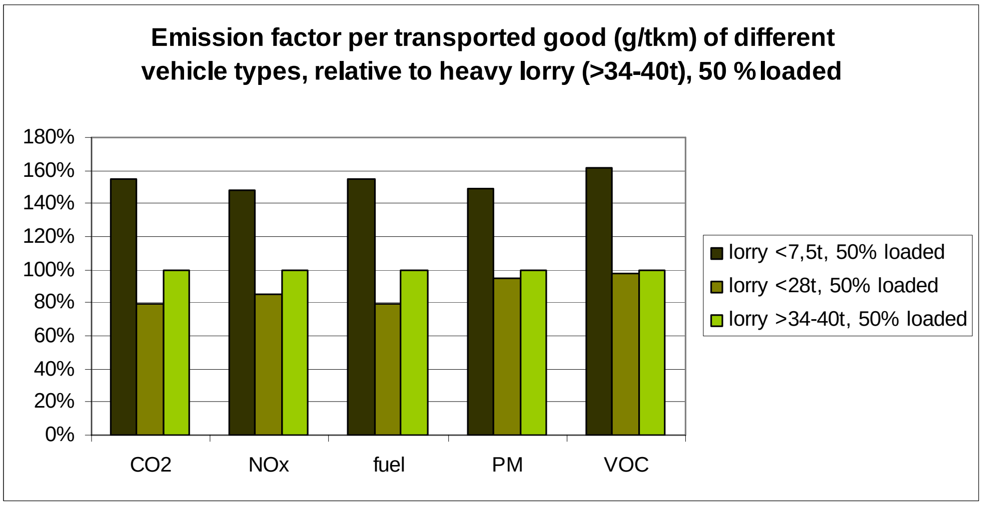


Figure 4: Emission factor of different vehicle types per ton transported good over 1 km distance (“tkm”). Own assumption for the transported volume. Emission factor of heavy lorries per tkm (>34-40t) = 100 %. Degree of loading: 50 %.

Now the light vehicles show the highest values in the emission factors. The higher values of the lorry < 28 t compared to the heavy lorry (> 34-40 t) contratticts the results of “ecoinvent” and can be caused by the weaknesses of the own assumptions for the loading capacities of the different vehicles.

7.1.4 Influence of the operation mode

We have not considered so far the influence of the operation mode on the emission factors. Figure 5 shows the CO_2 emission factor for the average lorry against different road conditions and traffic scenarios.

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[1] own assumption, since [HBEFA V2.1, 2004] and [Hausberger 2003] do not quote the transported volume of the different vehicle types: maximum loading capacity = three quarter (75%) of the maximum total mass

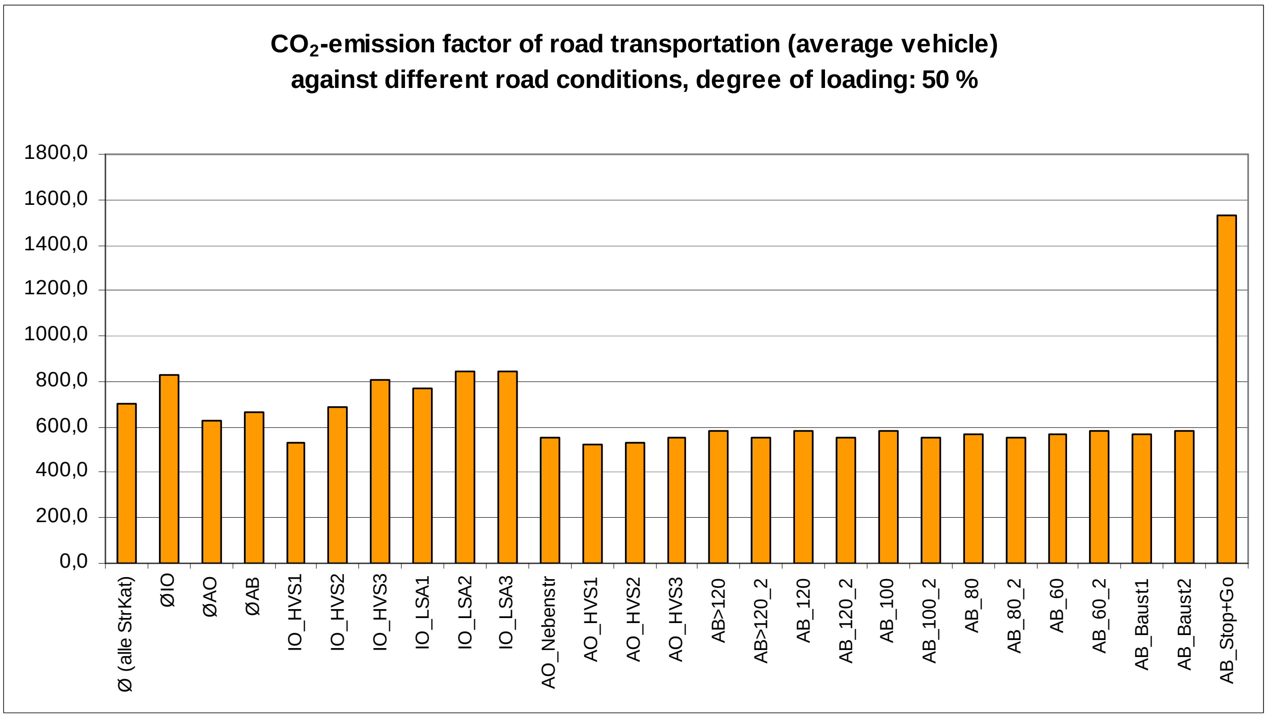

Figure 5: CO_2 emission factor in g/km of the average vehicle against different road conditions and traffic scenarios. The results are similar for the other considered emission factors.
IO…urban, AO…extra urban, AB…highway (Autobahn), Ø…average weighted by the kilometrage, LS…side roads, figure = velocity, e.g. AB_120: transportation on highway with 120 km/h

In extra urban conditions the emission factors are not particularly sensitive to the velocity as long as the traffic is fluid, but are considerably influenced by stop-and-go-situations (holdups on highways (“AB-Stop+Go”) and urban side roads (“IO_LS”).

7.1.5 Influence of the incline of the road

Another important factor is the incline of the road. The emission factor is reduced with negative and raised with positive incline. The relative modification is dependent on the degree of loading.

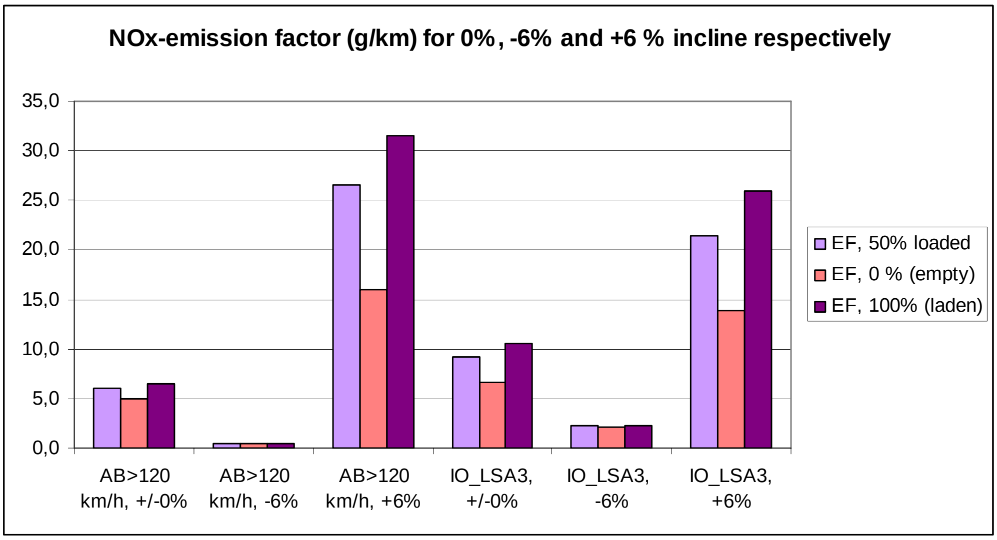

Figure 6: NO_X-emission factor for the average vehicle against 0%, - 6% and + 6% incline respectively using the scenarios highway “AB>120 km/h” and urban side road “IO_LSA3”.

7.2 Results based on ecoinvent

7.2.1 General remarks

On the contrast to the “Handbook”, “ecoinvent” always considers the whole life cycle of transportation processes. That means it includes the operation phase as well as the manufacturing of infrastructure and means of transport, their mantainance and disposal. Unless otherwise noted the transportation systems are always related to the transportation of 1 ton freight over 1 kilometer (1 tkm).
In the first two chapters the LCIA of rail and road transport are investigated more in detail. For the ship transport no detailed data for the different life cycle stages are available for this study[2]. Therefore only a comparison between inland navigation and ocean transport is possible. Finally the environmental impacts of the different means of transport are compared.

7.2.2 LCIA of rail transport

In ecoinvent the LCA of the process ‘transport, freight, rail A (Austria)’ comprehends the following life stages:

- manufacturing of locomotive, good wagons and railway track
- maintainance of locomotive and goods wagon
- operation and maintainance of railway track
- operation of freight train
- disposal of locomotive and railway track

Figure 7 a) shows the percentage that the different life stages contribute to the total burdens of the freight train within a particular impact category. In order to get a feeling for the relative importance of the specific impact in the various indicators Figure 7 b) compares the impacts of the rail transport to lorry transport (lorry >32t, Euro 3). If the percentage of the train transport is high compared to lorry transport (e.g. primary energy content of renewable energy sources) the indicator has presumably more importance.

As can be seen from the graphs the operation contributes at least 50 percent to each environmental impact except to the toxicity indicators. The toxicity indicators are also significantly influenced by the environmental impacts of the manufacturing processes especially that of the wagons. In an investigation with the objective of optimising the environmental performance of rail transport this could be closer looked at. The highest importance (compared to road transport) has the consumption of renewable primary energy. This indicator is mainly affected by the operation phase and is caused by the relatively high amount of renewable energy in the Austrian electricity mix what is conventionally regarded to be a positive environmental effect. In order to interprete this data we should therefore have a look at the total energy consumption (PEC total). The PEC total of the rail transport is significantly lower then that of the road transport (25 %) so that the high consumption of renewable energy sources can be interpreted as a positive environmental effect.

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[2] I failed to get the LCIA data of ship transport broken down to life stages out of SimaPro.

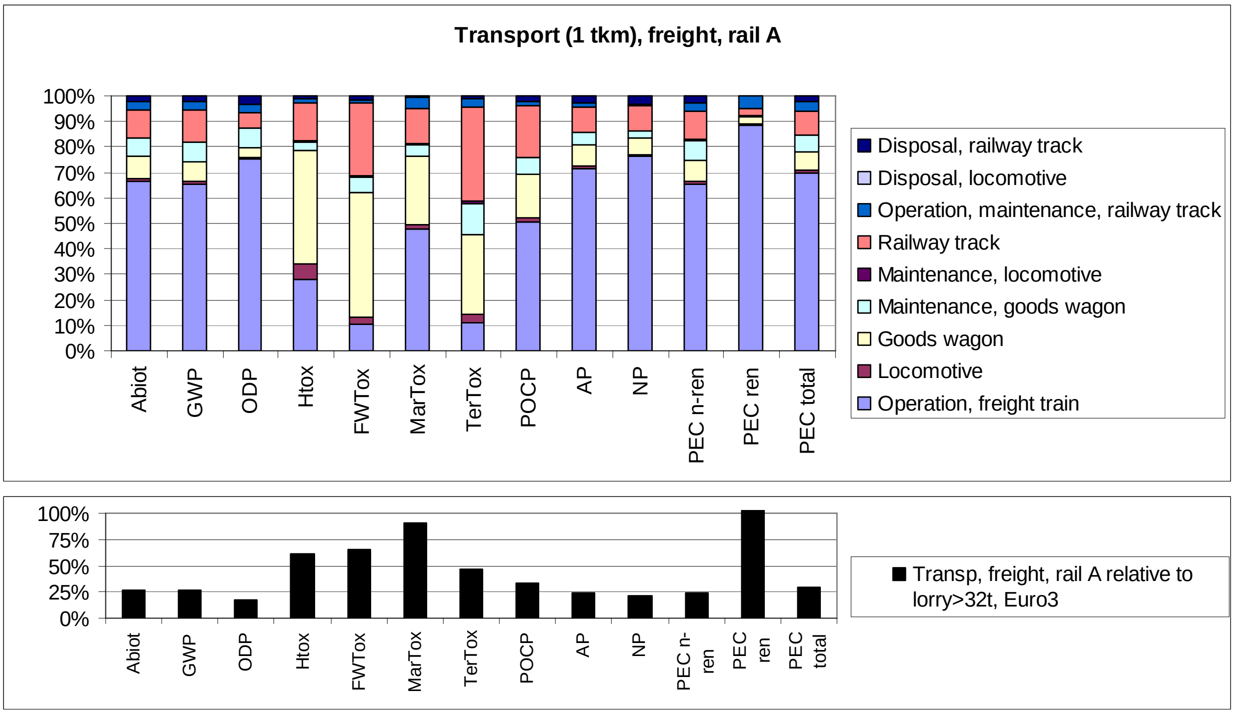

Figure 7 a) Relative contribution of each life stage to the LCIA of freight train per tkm. Figure b) relative environmental impacts of the rail transport compared to road transport (lorry >32t, Euro 3).

Trains are mainly operating with electricity in Austria nowadays, but there are still trains in side tracks operating with diesel. Figure 8 shows the LCIA of freight trains operating with European electricity mix (RER), Austrian electricity mix (A) and diesel respectively.

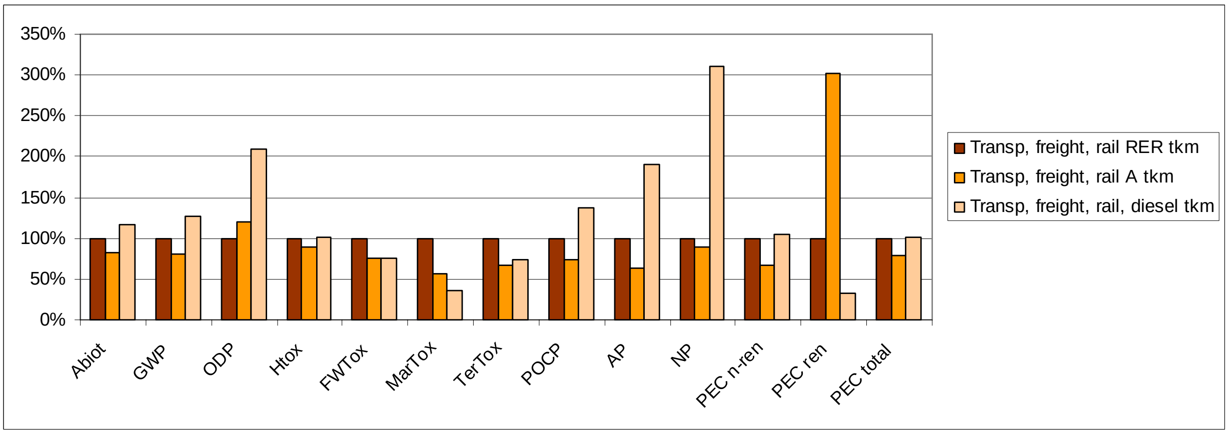

Figure 8: LCIA of freight train operating with different energy sources: electricity from RER (European electricity mix), A (Austria) and diesel.

The operation with diesel causes by far the highest environmental impacts except in the toxicity indcators and in the use of renewable primary energy. Austrian electricity mix is the most environmentally friendly energy source except in the impact categorie “ozone depletion potential” (ODP)[3].

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[3] To my point of view the relevance of the ODP indicator and the absolute value of $3{,}2*10^{-9}$ kg CFC11-equivalents has to be questionned since ozone destroying substances are completely forbidden in Austria.

7.2.3 LCIA of road transport

For the road transport the following life stages are considered in “ecoinvent”:

- manufacturing and maintainance of lorry
- building of road
- operation and maintainance of road
- disposal of road and lorry

Figure 9 shows the percentage that the different life stages contribute to the total burdens of the lorry within a particular impact category, figure a) for the lightest lorry (3,5-7,5t) and figure b) for the heaviest lorry (>32t).

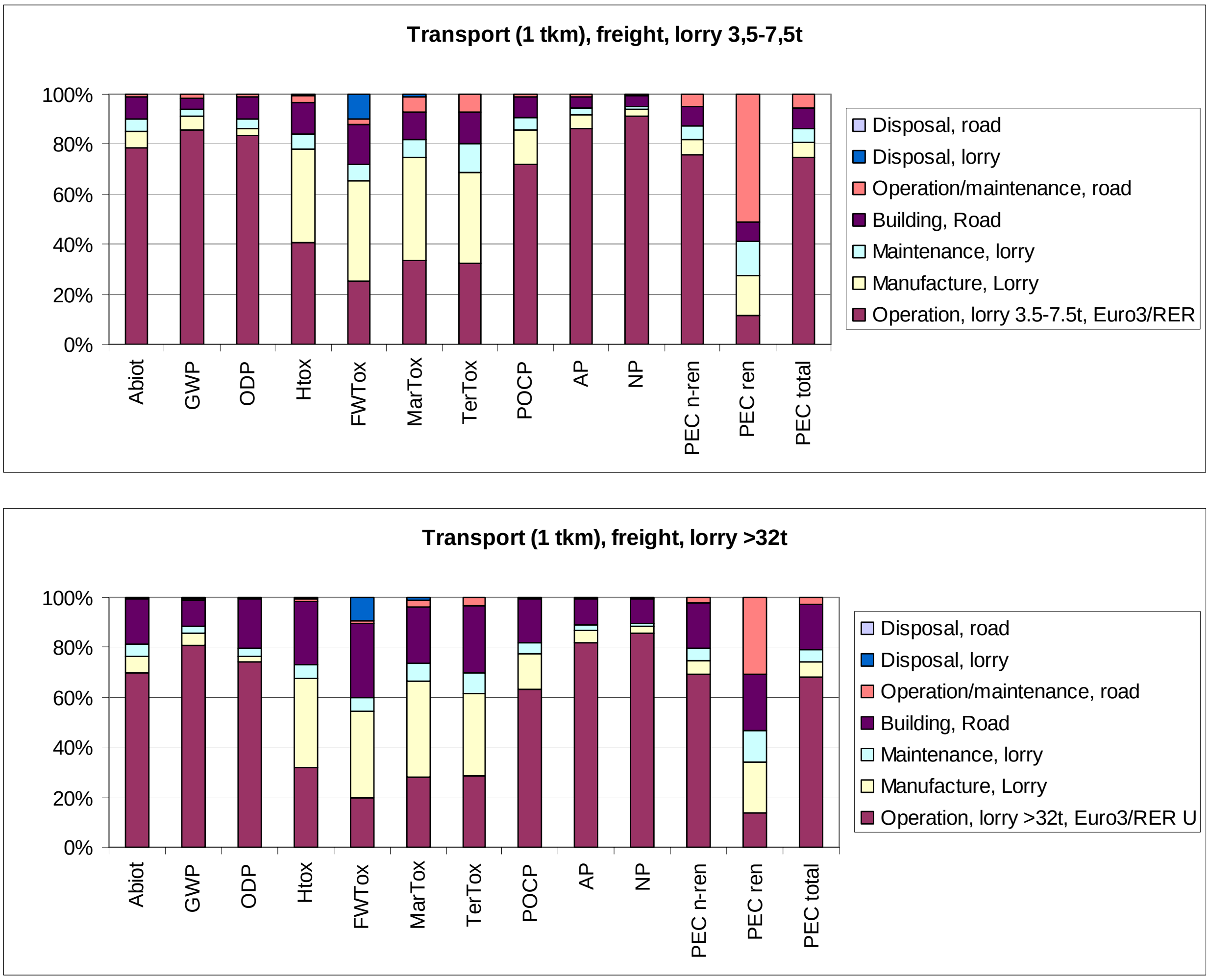
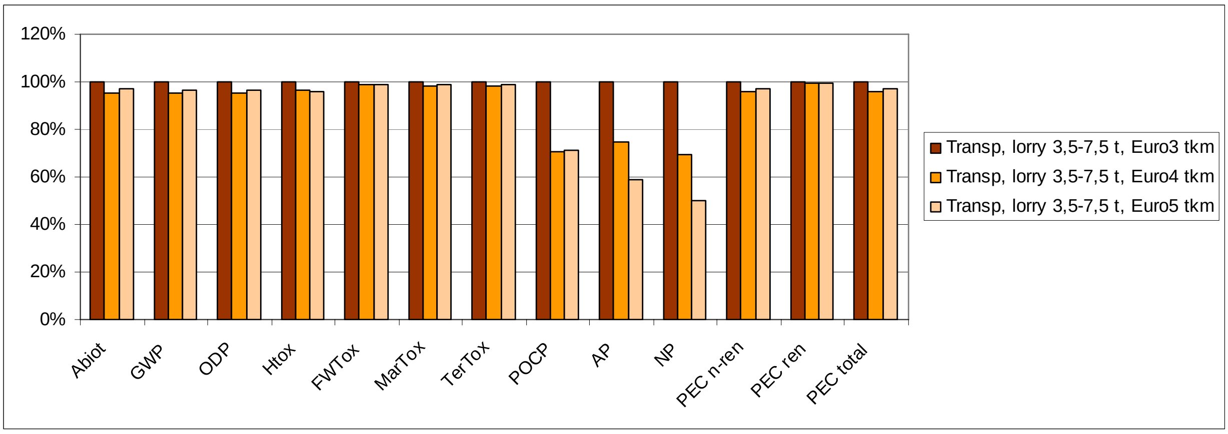


Figure 9: Relative contribution for each life stage to the LCIA of road transport per tkm. Figure a) for the lightest lorry (3,5-7,5t), figure b) for the heaviest lorry (>32t)

As we have already learned from the LCIA of rail transport the operation contributes the main part to the environmental impacts except for the toxicity indicators and in case of road transport also for the primary energy content on renewable resources (PEC ren). Again the toxicity indicators are also significantly influenced by the manufacturing processes.
The differences in the environmental impact categories for the different Euro classes 3, 4 and 5 is shown in Figure 10, figure a) for the lightest lorry (3,5-7,5 t) and figure b) for the heaviest lorry (>32 t).



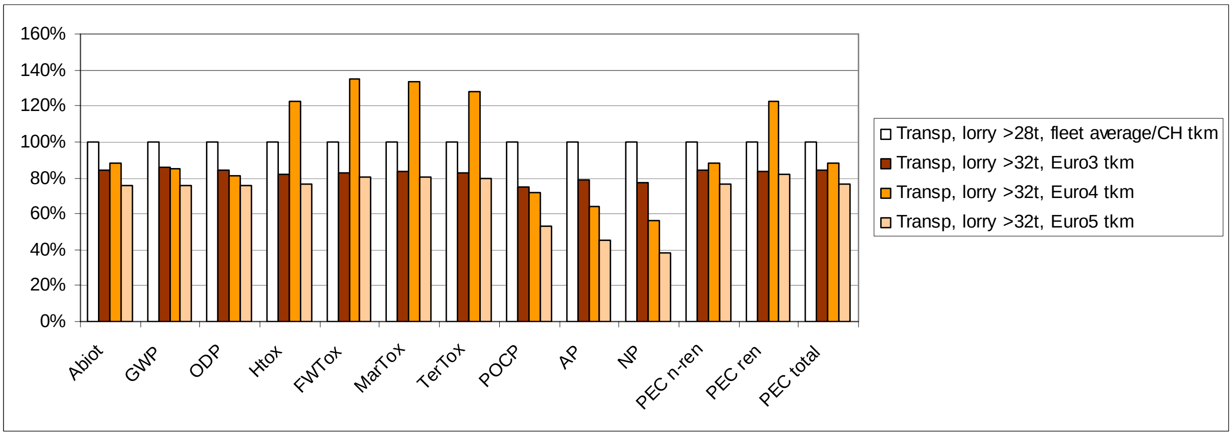


Figure 10: Environmental impacts of lorries with different emission classes (Euro 3, Euro 4 and Euro 5). Figure a) for lorry 3,5-7,5t, Euro 3 = 100%. Figure b) for lorry>32t compared to fleet average lorry >28t (= 100%)

Figure 10a) shows the same behavior as derived from “Handbook”: While most of the environmental indicators remain more or less the same, the POCP, AP and the NP (all dependent on VOC and NO_X emissions) diminish significantly with the later emission standards. Surprisingly the toxicity impacts are rising tremendously from Euro 3 to Euro 4 in Figure 10b). Especially for the human toxicity simple considerations would have expected a significant decrease due to the stronger restriction of PM_{10}-emissions. Maybe there is a correlation with the also increasing primary energy content on renewable resources.

7.2.4 LCIA of ship transport

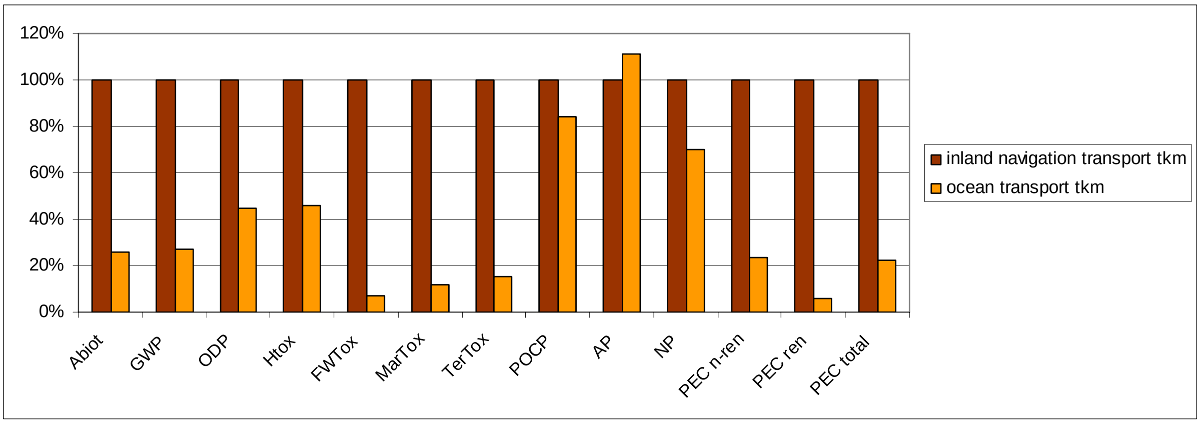


Figure 11: Environmental impacts of inland navigation transport (=100 %) and ocean transport

Figure 11 makes a comparison between the environmental impacts of inland navigation transport and ocean transport per tkm. Except for the acidification potential (AP) the ocean transport causes less environmental impacts than inland navigation transport. The reasons could be the higher loading capacity and the barrier-free tracks (e.g. no barrages).

7.2.5 LCIA of different modes of transport in comparison

Figure 12 shows the environmental impacts of different means of transports. The by far highest impacts are caused by the light lorry (3,5 – 7,5 t). Since these impacts overlie the impacts of the other means of transport the light lorry is excluded in Figure 13.

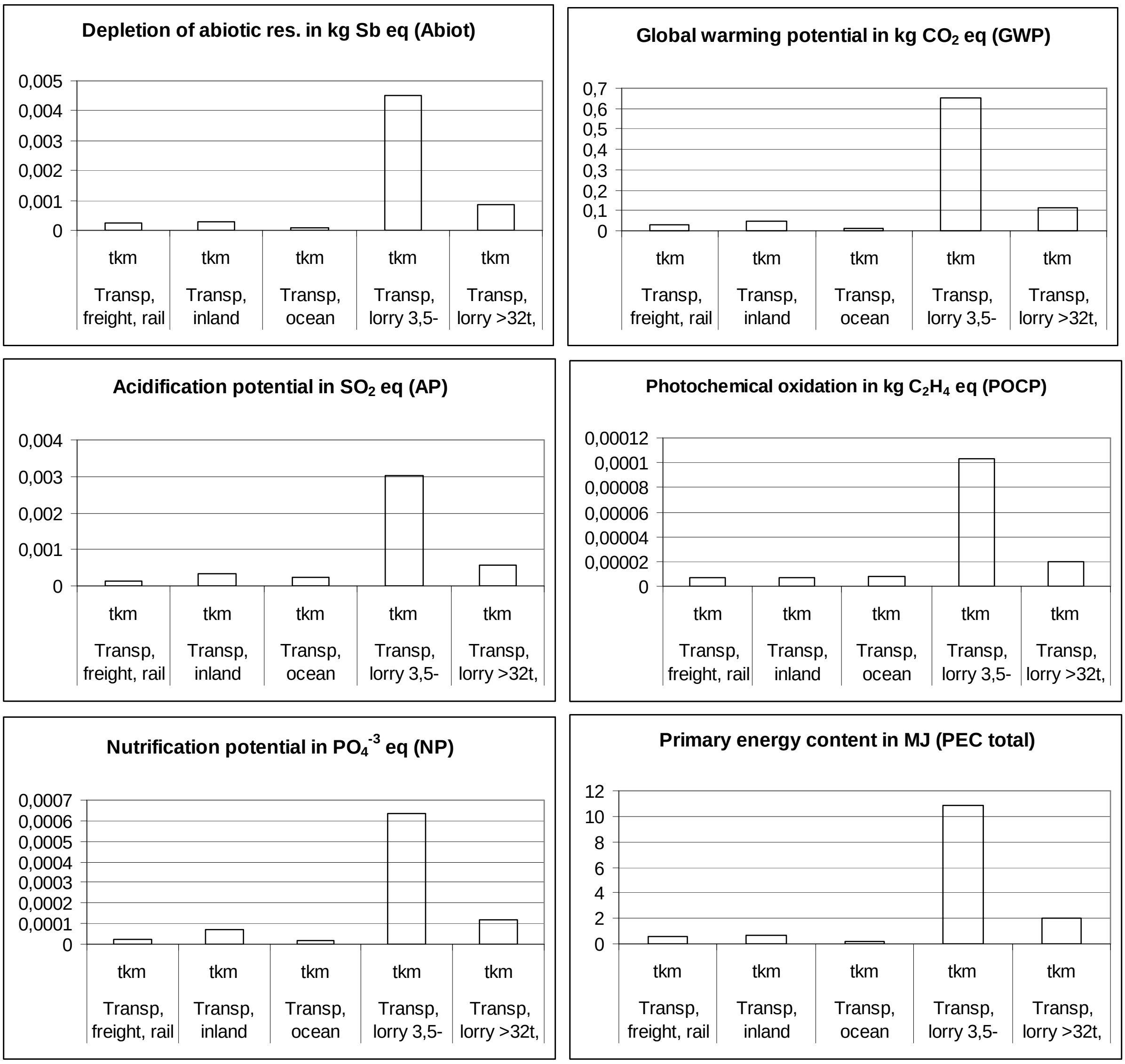


Figure 12: Environmental impacts of rail transport (transp, freight, rail), inland navigation (transp, inland), ocean transport (transp, ocean) road transport with lorry 3,5-7,5t (transp, lorry 3,5-) and with lorry > 32t.

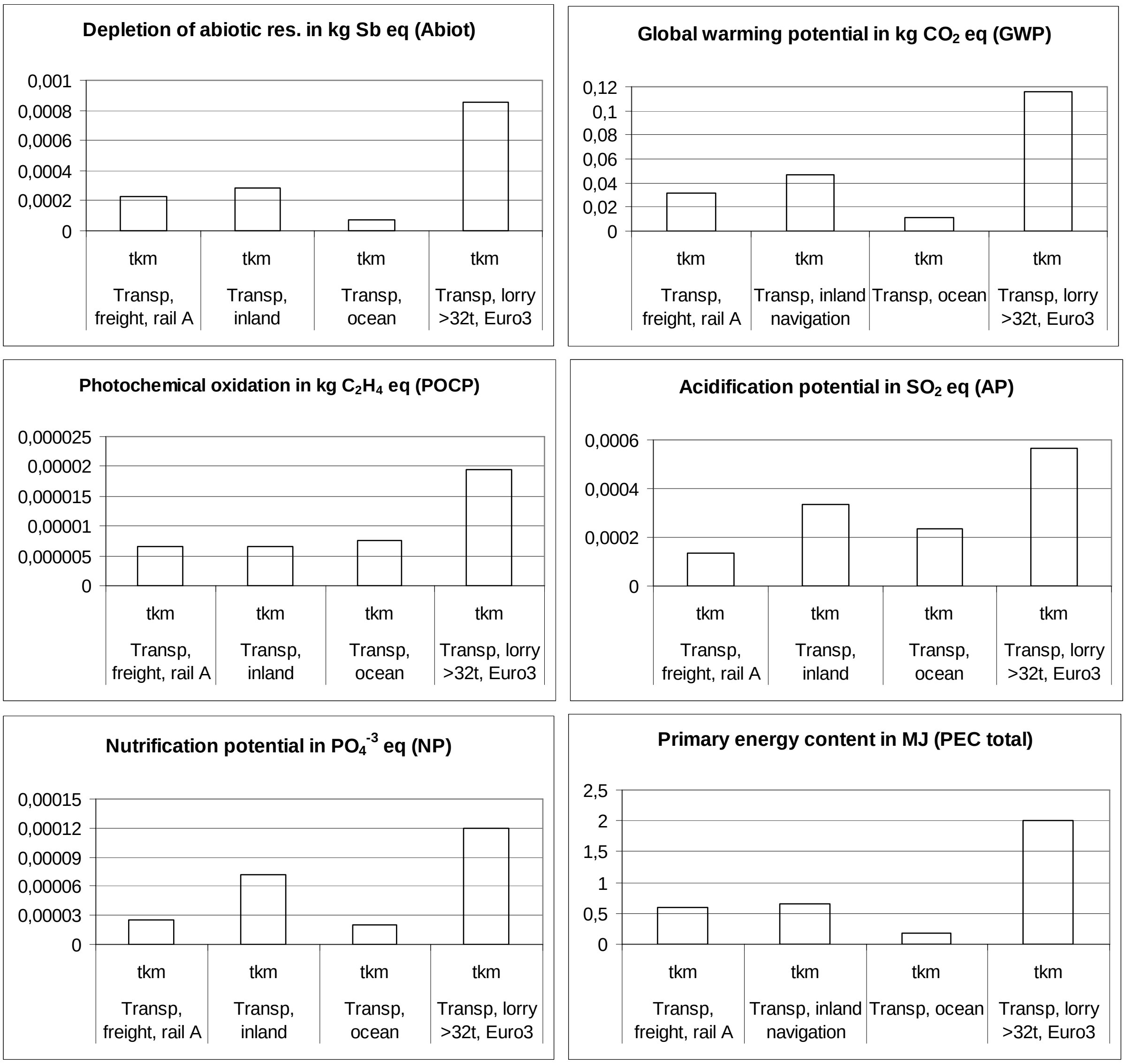


Figure 13: Environmental impacts of different means of transport (see Figure 12) without lorry 3,5-7,5t.

As can be seen from the graphs the road traffic causes the highest environmental impacts in all considered categories. The best environmental profile goes either to the rail transport or to the ocean transport depending on the regarded impact category. The rail transport benefits from the relative high amount of renewable energy in the Austrian energy mix.

8. Conlusions

8.1 Conclusions based on “Handbook”

- The PM-, VOC- and NO_X-emissions from Euro 4 vehicles are considerably lower than those from older vehicle models. On the contrary the CO_2-emissions and the fuel consumption have not improved notably since the 1980s. These parameters could be efficiently reduced by new fuel concept as gas, electricity, hybrid or solar mobiles which are not considered by the “Handbook” so far.

- Because of their high net weight heavy lorries show relatively high emission factors if they are driven empty. Therefore a high capacity utilisation is even more important for heavy lorries.
- Related to the provided benefit heavier lorries perform better than light lorries because of their higher loading capacity.
- In extra urban conditions the emission factors are not very sensitive to the velocity as long as the traffic is fluid, but they are considerably influenced by stop-and-go-situations (holdups on highways (“AB-Stop+Go”) and urban side roads (“IO_LS”)
- The emission factors seem to be more sensitive to the incline than to any other of the considered parameters[4] and raise with increasing incline. This fact should be looked at distinctly in mountained regions.

8.2 Conclusions based on “ecoinvent”

- As has been shown for road and rail transport the operation phase contributes at least 50 percent to the environmental impacts over the whole life cycle. Only the toxicity indicators are also significantly influenced by the environmental impacts of the manufacturing processes especially the manufacturing of the wagons.
- In the comparison of trains operating with Austrian electricity mix, European electricity mix and diesel, the trains operating with diesel cause by far the highest environmental impacts except in the toxicity indcators and in the use of renewable primary energy, where the trains operating with European electricity mix display the worst performance. Austrian electricity mix is the most environmentally friendly energy source for trains.
- While most of the environmental indicators remain more or less the same, the photochemical oxidation potential (POCP), acidifiation potential (AP) and nutrification potential (NP) (all dependent on VOC and NO_X emissions) diminished significantly from class Euro 3 to Euro 4.
- Road traffic causes the highest environmental impacts in all considered impact categories. The best environmental profile goes either to the rail transport or to the ocean transport depending on the regarded impact category. Compared to inland navigation the rail transport in Austria benefits from the relative high amount of renewable energy in the Austrian energy mix.

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[4] This matter could not be followed up within the frame of the term work

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