ecoinvent: Services

Life Cycle Inventories of Transport Services

Background Data for Freight Transport

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Abstract

Background, Goal and Scope. The ecoinvent database is a reference work for life cycle inventory data covering the areas of energy, building materials, metals, chemicals, paper and cardboard, forestry, agriculture, detergents, transport services and waste treatment. Generic inventories are available for freight and passenger transport including air, rail, road, and water transport. The goal of freight transport modelling is to provide background data for transport services, which occur between nearly any two process steps of a product system. This paper presents and discusses the model structure, basic assumptions and results for selected freight transport services.

Main Features. Transport services are divided into several datasets referred to as transport components. In addition to vehicle operation (comprising vehicle travel and pre-combustion), infrastructure processes such as vehicle maintenance, manufacturing and disposal, as well as transport infrastructure construction, operation and disposal, are also modelled. In order to link the various transport components to the functional unit of one tonne kilometre (tkm), so-called demand factors are determined. In the case of transport infrastructure that is not exclusively used by freight transport, allocation is essential. The respective allocation parameters employed for line infrastructure construction/disposal and operation datasets (including land use) are yearly Gross-tonne kilometre performance (Gtkm) and kilometric vehicle/train performance.

Results are presented for selected environmental exchanges related to gaseous emissions (climate change gases, nitrogen oxides, and hydrocarbons), heavy metal (zinc and cadmium) emissions to soil and air, as well as BOD (Biological Oxygen Demand), and land use. Particle emissions are further distinguished into fine (PM2.5) and coarse (diameter between 2.5 and 10 µm) particles. The results presented comprise both an intra- and intermodal comparison.

Results and Discussions. A comparison of Swiss and European rail transport reveals considerably lower emissions from Swiss rail transport due to the almost exclusive use of hydropower as traction energy. For gaseous emissions, freight transport by water or rail exhibits considerably better performance than road transport (65–92% less gaseous emissions). As far as zinc and cadmium emissions to soil are concerned, water and rail transport produce less than 1% of the emissions resulting from road transport for either pollutant. For zinc and cadmium emissions to air, road transport has the highest emissions; however, the emissions due to water and rail transport range from 2 to 18% of the emission levels arising from road transport. Particle emissions show a more diverse pattern. Whilst fine particle emissions due to water and rail transport are considerably lower than road transport, rail transport with respect to coarse particles performs worse than road transport. Dominance analysis reveals the importance of infrastructure processes. For instance, the NMHC-emissions of infrastructure processes account for 40%, 30% and 50% of emissions for road, rail and barge transport, respectively. For the demand factor of infrastructure operation, a sensitivity analysis of the employed allocation factor was performed, revealing no sensitivity for gaseous emissions and particles. On the other hand, considerable changes in both emission levels and in the ranking of transport modes is observed for land occupation. Finally, we varied selected operation parameters for road transport, resulting in considerable reductions of CO_2 and NO_x emissions of up to 60%. In one extreme case (load factor: 100%), NO_x emissions for vehicle operation of a lorry are lower than for inland water transport. Only as a result of the considerably higher NO_x emissions occurring in infrastructure processes does road transport score worse than water transport, with the ranking remaining the same as for the generic data presented in ecoinvent 2000.

Conclusions and Perspectives. The provided datasets allow for a preliminary screening of the importance of transport processes within a product life cycle. In the cases for which transport processes are identified as sensitive for the overall outcome of certain product life cycle or for transport specific comparisons, the modular structure and transparent documentation of demand factors allows for an easy and transparent integration of more case-specific data for selected transport components.

Keywords: ecoinvent; life cycle database; life cycle inventory analysis; rail transport; road transport; Switzerland; transport comparison; transport modelling; water transport

1 Goal, Scope and Background

1.1 Background

Freight transport occurs between nearly any two process steps of a product system and is often of major importance for a product life cycle, as demonstrated with food LCAs (Jungbluth et al. 2000). Comprehensive life cycle inventories (LCI) of various modes of transport are available from Frischknecht (1996) and Maibach (1999). Within the framework of the ecoinvent 2000 project, these data have been extended, updated and harmonised (Frischknecht et al. 2004).

1.2 Goal, scope and functional unit

The main objective of transport modelling in ecoinvent Data v1.1 is to provide background data for transport services in order to complete a variety of product life cycles. Generic background data have been generated for four modes of transport (air-, rail-, road- and water transport) to account for cumulative exchanges due to the transportation occurring between two process steps of a product system. The data represent average transport conditions in Switzerland and Europe. In this paper, selected freight transport datasets representing heavy-duty road transport, rail transport and inland-waterway transport, as available from ecoinvent, are presented.

In order to quantify environmental exchanges of transport services and to relate transport datasets to other product life cycles, the environmental exchanges are related to the reference unit of one tonne kilometre [tkm]. A tonne kilometre is defined as the transport of one tonne of goods by a certain transport service over one kilometre. Passenger transport and intercontinental freight transportation are not presented in this paper.

2 Transport model and transport components

Each mode of transport is further separated into sub-groups, referred to as transport services, using several criteria such as geographical operation (e.g. rail transport), vehicle size (e.g. road transport) and transported goods (e.g. water transport). The general model structure is illustrated in **Fig. 1** using the example of road transport.

The modelled transport components (p_i, i=1…7) are linked in a unit process (p_T) referred to in the database as 'transport, transport service' (e.g. transport, lorry 16 t). In order to link various transport components to the reference flow of one tonne kilometre (tkm), so-called demand factors d_j are determined. Cumulative LCI results for a transport service, x_i^T per tkm are calculated as follows:

$$x_i^T = \sum_{j=1}^{n} \frac{x_i^j}{r(p_j)} \cdot d_j \qquad (1)$$

where n denotes the number of transport components and $x_i^j / r(p_j)$ indicates the cumulative environmental exchanges (x_i, e.g. CO_2 to air) of a certain transport component (unit process p_j) related to its reference flow ($r(p_j)$, e.g. manufacturing of one lorry).

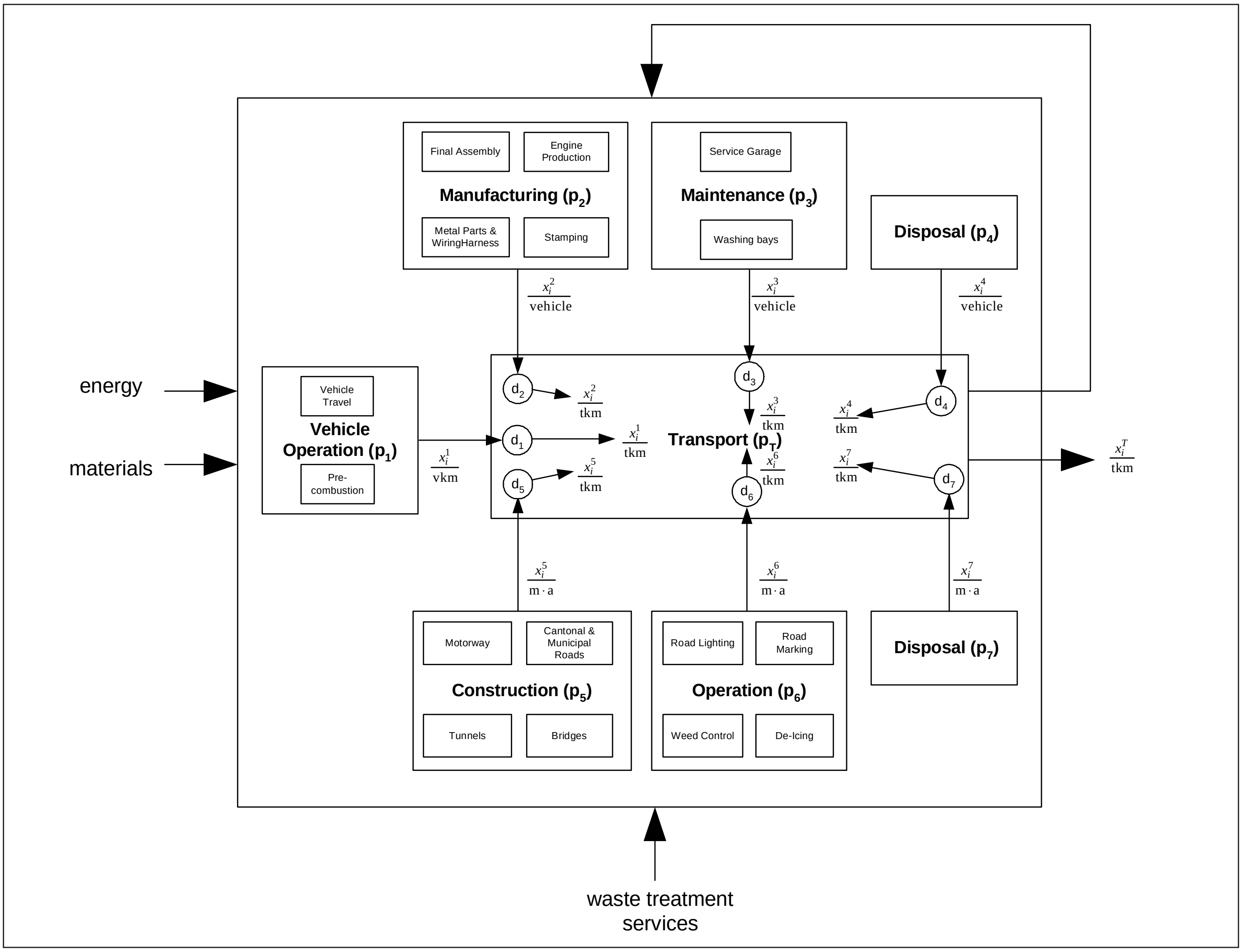

Fig. 1: Principle model structure and transport components and their interrelationship

2.1 Operation of vehicles

Unit processes referred to as 'Vehicle Operation' (p_1) account for both direct environmental interventions due to vehicle travel (predominately airborne emissions) and pre-combustion of fuels. Carbon dioxide emissions are directly derived from the carbon content of the used fuel. For the determination of combustion process specific emissions, such as HC, CO, NO_x and particles, various sources of literature are used and documented in Spielmann (2004). Where further information was available, specific hydrocarbon emissions have been calculated. Emission factors for particles comprise both exhaust and non-exhaust emissions (e.g. the abrasion of tyres, of brakes and of the road or rail surface). Heavy metal emissions due to trace elements in fuels and tyre are also accounted for. Environmental exchanges due to the pre-combustion of fuels, including transportation to petrol stations, are available from Jungbluth (2003).

Heavy-duty road transport is modelled using a bottom-up procedure, taking into account differences in vehicle size and emission standards. The data are aggregated to represent three Swiss and two European heavy-duty transport services. The kilometric performance of vehicle sub-categories in the year 2000 is used as a weighting factor. Fuel consumption as presented in **Table 1** and emissions of regulated pollutants (HC, NO_x and PM10) are calculated based on data available from Keller (2000) and Giannouli (2003) representing Swiss and European conditions, respectively. According to Frischknecht (2004), exhaust PM10 emissions are further split into fine (PM2.5) and coarse (aerodynamic diameter between 2.5 and 10 µm) particles. For diesel exhaust particles, we assume a PM2.5/PM10 ratio of 92.3% (Spielmann et al. 2004). For the calculation of specific hydrocarbon emissions, the following fractions are assumed: 2.4% methane and 1.9% benzene (in accordance with the benzene content of fuel in the year 2000). The inputs and outputs of the operation datasets are related to the vehicle's kilometric performance (vkm) and hence allow for case specific adjustment of the default load factor.

Inputs and outputs for the operation datasets of rail and water transport are directly related to the functional unit of one tonne kilometre; i.e. the load factor cannot be adjusted. Rail operation comprises both traction and shunting processes. Swiss rail transport is represented by an average Swiss freight train, determined with the use of a top-down procedure based on yearly performance figures and traction energy consumption. Freight transport in Switzerland is exclusively performed by electric trains; diesel locomotives are used only for shunting. European rail transport is a mix of diesel and electric traction. Energy consumption figures and emission indices for the two train types are available from Borken (2003). The employed consumption figures of electricity and diesel (see Table 1) is based on German performance and consumption figures (Spielmann et al. 2004). Non-exhaust particle emissions due to the abrasion of rail tracks, wheels, brakes and overhead contact lines are taken into account and are based on Swiss conditions.

Average inputs and outputs of inland waterway transport are determined in a bottom-up manner on the basis of diesel consumption figures available from Dorland (2000), as cited in Bickel (2001). However, the available data distinguishes various weight-classes of barges and, hence, further aggregation is essential. The required aggregation to an average barge is achieved by employing the total yearly carrying capacity of each class, as available from (ZKR 2003), as a weighting factor. The amount of various gases emitted into the atmosphere is directly related to total fuel consumption. Emission indices for process-specific airborne emissions are taken from Dorland (2000), as cited in Bickel (2001). For the calculation of specific hydrocarbon and exhaust heavy metal emissions, as well as for the further split of PM-emissions, we applied the same assumptions as for heavy-duty road transport.

2.2 Vehicle fleet

Environmental interventions of the vehicle fleet (lorries, locomotives and wagons, barges) are calculated for three components: manufacturing, maintenance and disposal of a vehicle. The reference unit is one vehicle [unit]. The data is predominately obtained from Frischknecht (1996) and Maibach (1999). For the manufacturing of road vehicles, more detailed data is utilised comprising final assembly, engine production, metal parts and wiring harness, as well as stamp-

Table 1: Final energy consumption for vehicle travel. The energy values are based on the lower heating values of diesel fuels (42.8MJ/kg diesel)

Mode of Transport	Transport Service	Diesel Kg/tkm	Electricity [1] KWh/tkm	Final Energy Consumption MJ/tkm
Rail	Average CH		0.062	0.22 [2]
	Average RER	0.002	0.040	0.23 [2]
Road	Lorry 16t CH	0.072		3.08
	Lorry 28t CH	0.050		2.14
	Lorry 40t CH	0.036		1.54
	Lorry 16t RER	0.089		3.81
	Lorry 32t RER	0.038		1.63
Water	Barge	0.009		0.38

[1] The presented energy figures account for a transformation loss of 15%.

[2] The final specific energy consumption for electric railways in Europe is assumed to be lower than the Swiss average. Thus, the higher specific fuel consumption of diesel locks which are still in operation in Europe is compensated for.

ing (Spielmann et al. 2004). In addition, material and energy consumption due to the construction and disposal of buildings are modelled using datasets available from Kellenberger (2004). For maintenance of rail vehicles, new data is presented based on the consumption of stationary energy and materials available from the service garages of the Swiss Federal Railways (SBB). Data for barge manufacturing and maintenance are based on Maibach (1999). Vehicle disposal is only addressed superficially on the basis of the material composition of vehicles. For metals, cut-off allocation is applied, whereas the disposal of non-metal bulk materials is addressed in the corresponding disposal datasets.

2.3 Transport infrastructure

Transport infrastructure is modelled using three components: construction, operation and disposal of transport infrastructure. For line infrastructure (road and rail networks), data is expressed in one metre and year [ma]; for point infrastructure (port and airport), the reference unit is [m^2a]. Construction data comprises material, energy and transport expenditures (Maibach et al. 1999). For line infrastructure, civil engineer works (i.e., tunnels and bridges) are also taken into account. The share of tunnels on the road network differs considerably for different road types. For Swiss motorways, we calculated a share of pipes of 147 m/km. In contrast, for third class roads, a share of 0.7 m/km is calculated. Thus, we calculate a tunnel share of 3.71 m/km for an average Swiss road. For rail infrastructure, the corresponding figure is 70 m/km. The average share of bridges is 30.0 m/km and 3.7 m/km for rail infrastructure and road infrastructure, respectively. Expenditures for the construction of bridges are taken from von Rozycki (2003). Detailed assumptions and references concerning the share of bridges and tunnels, as well as the life span of various infrastructure components, are documented in Spielmann (2004).

The inventory for road operation comprises exchanges due to de-icing, weed control, road marking (5.3E-03 kg/(m*a) NMVOC) and road lighting. For rail infrastructure, we include weed control as well as electricity consumption and lubricant application for point operation, assuming a point density of 1.205 km^{-1}. Expenditures per point are taken from von Rozycki (2003). Electricity consumption due to ventilation in long alpine tunnels is taken from Maibach (1999). For port infrastructure, we take into account oil spills (100 kg/a) occurring in the port area, as well as electricity consumption. Infrastructure expenditures for artificial inland waterways (canals) are also included. The datasets 'operation, infrastructure' include direct land occupation due to the existing transport infrastructure (e.g. roads). For road- and rail infrastructure, we account for a total direct land occupation of 7.8 m^2a/ma and 21.9 m^2a/ma, respectively. For water transport, direct land occupation comprises port infrastructure (59'500'000 m^2a/port) and artificial waterways (62 m^2a/ma). Infrastructure disposal is addressed only superficially. The figures for port and road disposal take into account the excavation and transport of deconstructed material, and assume a complete reuse and recycling of materials. For rail infrastructure, material disposal of inert material landfill is accounted for. Furthermore, we assume that 20% of the excavated gravel and sand of rail infrastructure is disposed of at residual material landfills. A specific model for these sites is available from Doka (2004).

2.4 Demand factors

In **Fig. 2**, the various pieces of information along with their interrelationships – essential for the calculation of demand factors, d_j – are illustrated for the case of road transport.

For the operation of road vehicles (d_1), the ratio vkm/tkm is calculated on the basis of the average load. Load figures for lorries of various vehicle types and sizes are available from Knörr (2000). For the generic lorries modelled in ecoinvent, these figures are further aggregated by employing the yearly kilometric performance of different vehicle types and sizes as a weighting factor (Spielmann et al. 2004). Demand factors for vehicle fleet components, i.e. vehicle manufacturing (d_2), vehicle maintenance (d_3) and vehicle disposal (d_4), with d_2=d_3=d_4, are calculated as the inverse of the vehicle's lifetime transport performance. Thus, assumptions of the lifetime kilometric performance and average load factor are required. These figures differ according to transport mode. For example, the lifetime performance of a barge and a 40 t lorry is 1.24E+06 km/vehicle and 5.4E+05 km/vehicle, respectively, and the average load is 1000 t/vehicle and 9.68 t/vehicle, respectively.

The demand factor for road transport infrastructure is calculated taking into account the total length of the Swiss or European transport networks (7.11E+04 km and 3.24E+06 km, respectively) and the total Swiss or European road transport performance (5.64E+10 vkm and 2.87E+12 vkm, respectively). For rail transport, the rail network (2300 km two-way tracks) and transport performance (5.94E+10 Gtkm) of the SBB, accounting for about 98% of the freight transport on the Swiss network, are taken into consideration. Road and rail transport infrastructure is allocated to the different user types (passenger vehicles and goods vehicles). For construction, including the renewal (d_5) and disposal (d_7) of infrastructure, the yearly Gross-tonne kilometre performance (Gtkm) is employed as the allocation rule so as to account for the fact that damage, and hence the resulting renewal expenditure of roads, is mainly due to vehicle weight. In contrast, for the determination of demand factors of infrastructure operation datasets (d_6), the temporal occupation of the infrastructure (employing kilometric vehicle/train performance in the year 2000 as a first approximation) by different user types, irrespective of the vehicle weight, is used as the allocation principle. The required performance figures are available from national statistics, with the exception of the Gross-tonne performance of road vehicles, which is determined by the authors. For example, in order to determine the Gtkm of a European 32 t lorry, the following assumptions are made: Net vehicle weight is 18 t, average load is 7.0 t, resulting in an average Gross-tonne vehicle weight of 25.0 t. Based on these figures, we obtain a

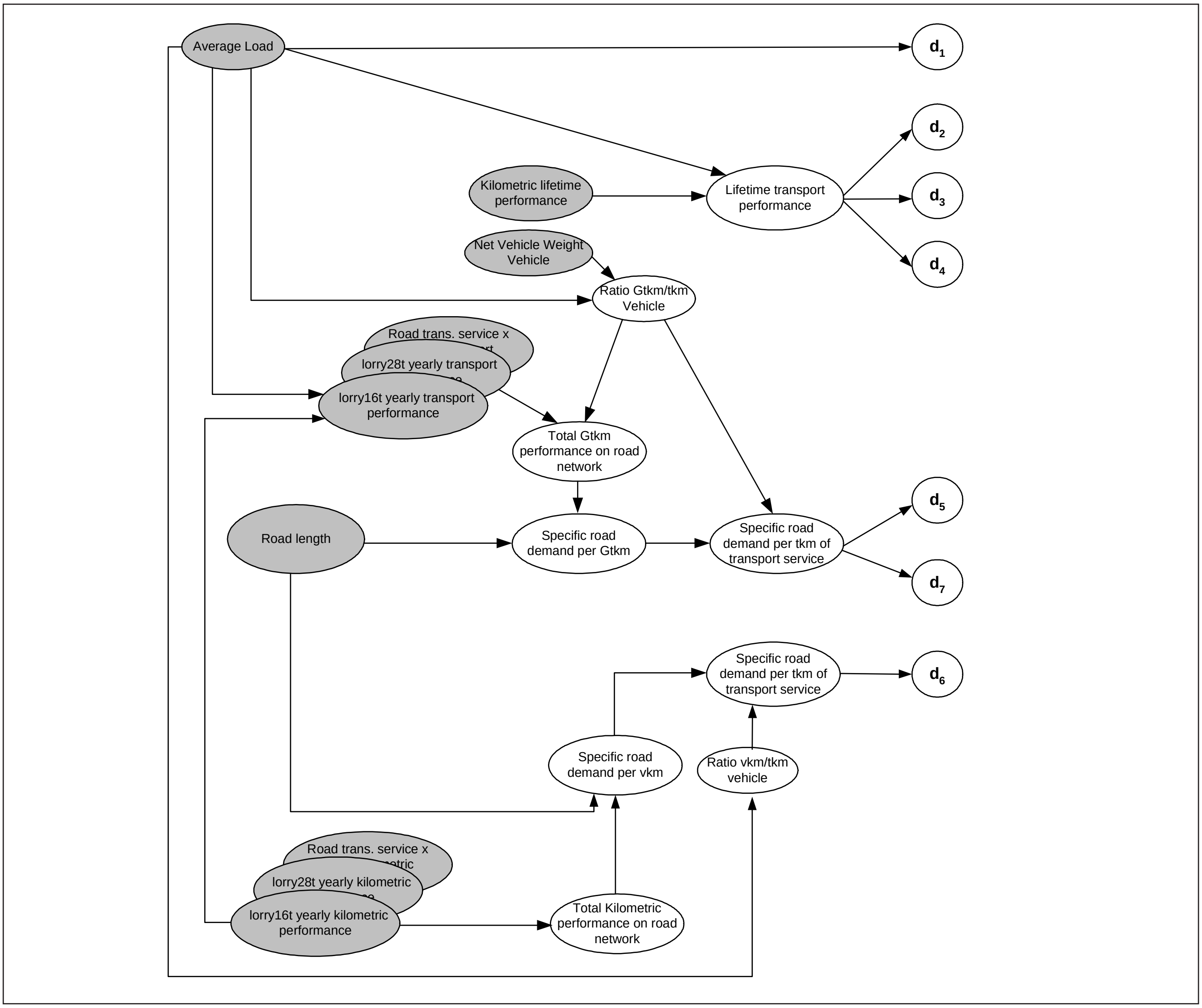

Fig. 2: Schematic illustration of information and factors essential for the determination of different demand factors. The grey fields present information available from statistics and literature. The white fields represent factors based on our own calculations

gross/net ratio of 3.56 Gtkm/tkm and, hence, a yearly Gross-tkm transport performance of 3.38E+12 Gtkm for the 32t lorry, assuming a net transport performance of 9.5E+11 tkm. The net transport performance is calculated based on a yearly kilometric performance of 1.35E+11 vkm (Giannouli 2003). For the entire European road network (including 32t lorries, 16 t lorries, vans, as well as passenger vehicles), we obtain a Gross-tkm performance of 8.87E+12 Gtkm resulting in a specific road demand per Gross-tkm of 3.65E-04 (m*a)/Gtkm. Based on these assumptions and figures, the specific road demand for the 32t lorry is calculated as 1.3E-03 (m*a)/tkm. For port infrastructure, the total cargo throughput is used to determine the demand factor. The total port infrastructure demand per transported tonne is calculated to be 3.18E-09 unit/t. In order to calculate the port demand for a barge, we assume an average transport distance of 250 km, resulting in a demand factor (d_j, j = 5,6,7) of 1.27E-11 unit/tkm.

3 Results and Discussions

Selected cumulative LCI results are presented and discussed in this section. Please note that only a small portion of the approximately 1000 elementary flows can be presented. The selection is focussed on transport relevant emissions, comprising gaseous emissions (climate change gases, nitrogen oxides, hydrocarbons), particle emissions (fine and coarse), heavy metal (zinc and cadmium) emissions to soil and air, as well as BOD (Biological Oxygen Demand) and land use. The presentation of results comprises an intra-modal as well as an inter-modal comparison. In order to allow for the presentation of a variety of exchanges characterised by different magnitudes, the results are illustrated using normalised emission scores (i.e. selection of one transport service as the reference service and setting its calculated cumulative emissions to 100%; the emissions of other transport services are then expressed by relation to the reference transport service). The use of the term normalised is not to be confused with its use in Life Cycle Impact Assessment.

3.1 Intra-Modal comparison

Fig. 3 illustrates the normalised emission scores (16 t lorry Switzerland = 100%) for road transport services, which are compared to vehicle weight and location of operation and rail transport services (Rail Europe = 100%).

For Swiss transport services, the 40 t class performs 55% and 65% better than the 16 t category. More dramatic differences are revealed when examining European transport services. The reason for this is the higher cumulative emissions of the European 16 t lorry compared with the Swiss 16 t lorry. For fuel content-dependent emissions, such as CO$_2$, characterised by a defined specific emission index (e.g. CO$_2$/MJ fuel) independent of the combustion process, the resulting 15% higher emissions of the European 16 t lorry are caused by the lower load factor of the European vehicle; i.e. higher consumption and emissions of heavier vehicles are compensated for by their higher load factor. For combustion process-dependent emissions, the discrepancies in emissions between the European 16 t lorry and the Swiss 16 t lorry (e.g. NMHC (60%) and particle (50%)) indicate basic differences in the employed model input data in addition to variations caused by a different load factor. As stated in section 2.1, specific emission factors for vehicle travel of European and Swiss vehicles are derived from two different data sources. The emission factors for Switzerland are derived from Keller (2000). These data have been recently updated (Keller et al. 2004), and now allow for a comparison on the level of different emission standards. European data are derived from Giannouli (2003). A comparison of the data available from Keller (2004) and Giannouli (2003) on the level of emission indices (e.g. NMHC/MJ fuel) reveals considerable differences. For instance, for hydrocarbon emissions, we calculated specific emission indices of 0.045 g/MJ and 0.035 g/MJ for a conventional and EURO 2 lorry (34–40 t), respectively, based on data available from Keller (2004). Employing data available from Giannouli (2003), the corresponding specific indices are 0.069g/MJ and 0.041 g/MJ, respectively. Moreover, assumptions about the kilometric performance distribution of vehicles with different emission standards (e.g. share of conventional and EURO2 vehicles) within vehicle sub-classes differ. For example, for a German lorry (34–40 t), Keller (2004) assumes a kilometric performance of 18% for conventional vehicles and 68% for EURO 2 vehicles. In contrast, Giannouli (2003) assumes a share of 67% for conventional and 18% for EURO2 vehicles. A further analysis, however, would require detailed information about measured emissions, transfer coefficients and traffic conditions, all of which are not readily available and which are beyond the scope of this paper.

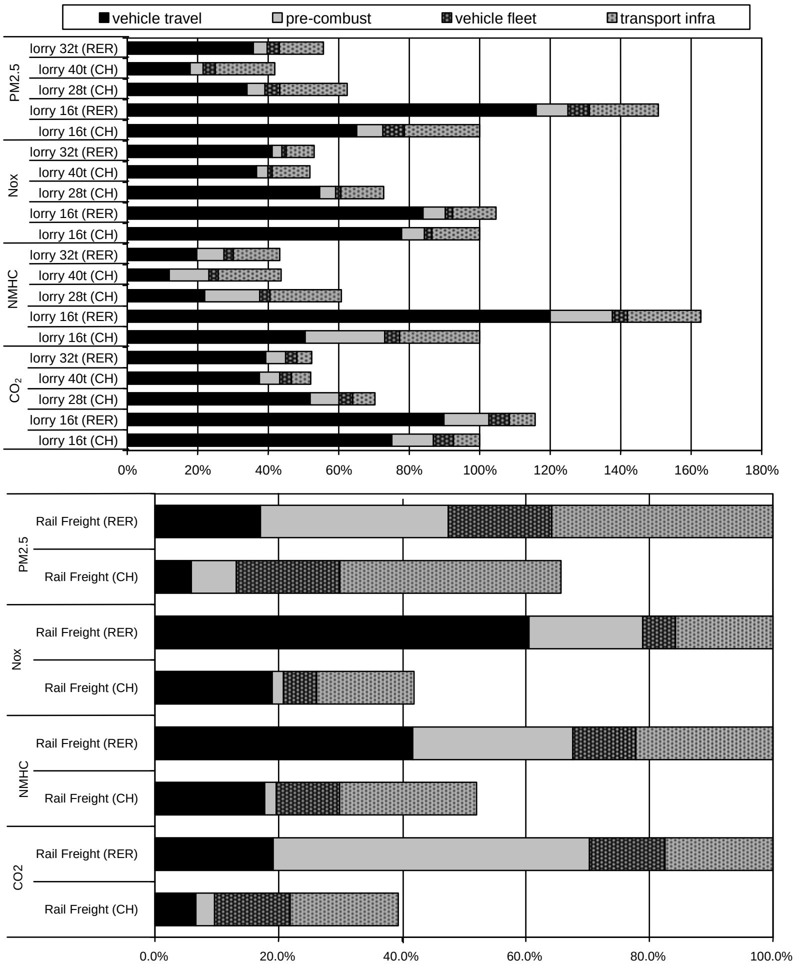

Fig. 3: Intra-modal comparison (normalised figures: 16t lorry (CH):= 100 % and Rail (RER) := 100%)

Furthermore, the presented figures illustrate the consequences of the higher road demand for Swiss transport services. For the heaviest vehicle classes, the lower emissions of the Swiss 40 t lorry due to operation are compensated by less busy roads in Switzerland, resulting in a higher road demand per transported tonne.

The comparison of Swiss and European rail transport indicates considerably better performance on the part of Swiss rail transport, while the specific energy consumption is almost the same as for the European average (see Table 1). This is due to the almost exclusive use of company-owned hydropower as traction energy. Vehicle travel gaseous emissions for Swiss rail transport are caused by diesel shunting locomotives.

3.2 Inter-modal comparison

The inter-modal comparison focusses on three European (RER) transport services: 32 t lorry (RER), Rail Transport (RER) and barge transport (RER). **Fig. 4** illustrates the normalised emission scores (32 t lorry = 100%). For simplicity and ease of figure presentation, and due to their low contribution to overall transport performance, the vehicle disposal unit process is included in vehicle manufacturing and the infrastructure disposal unit process is included in infrastructure construction.

For gaseous emissions, freight transport by inland waterways and by rail show considerably lower cumulative emis-

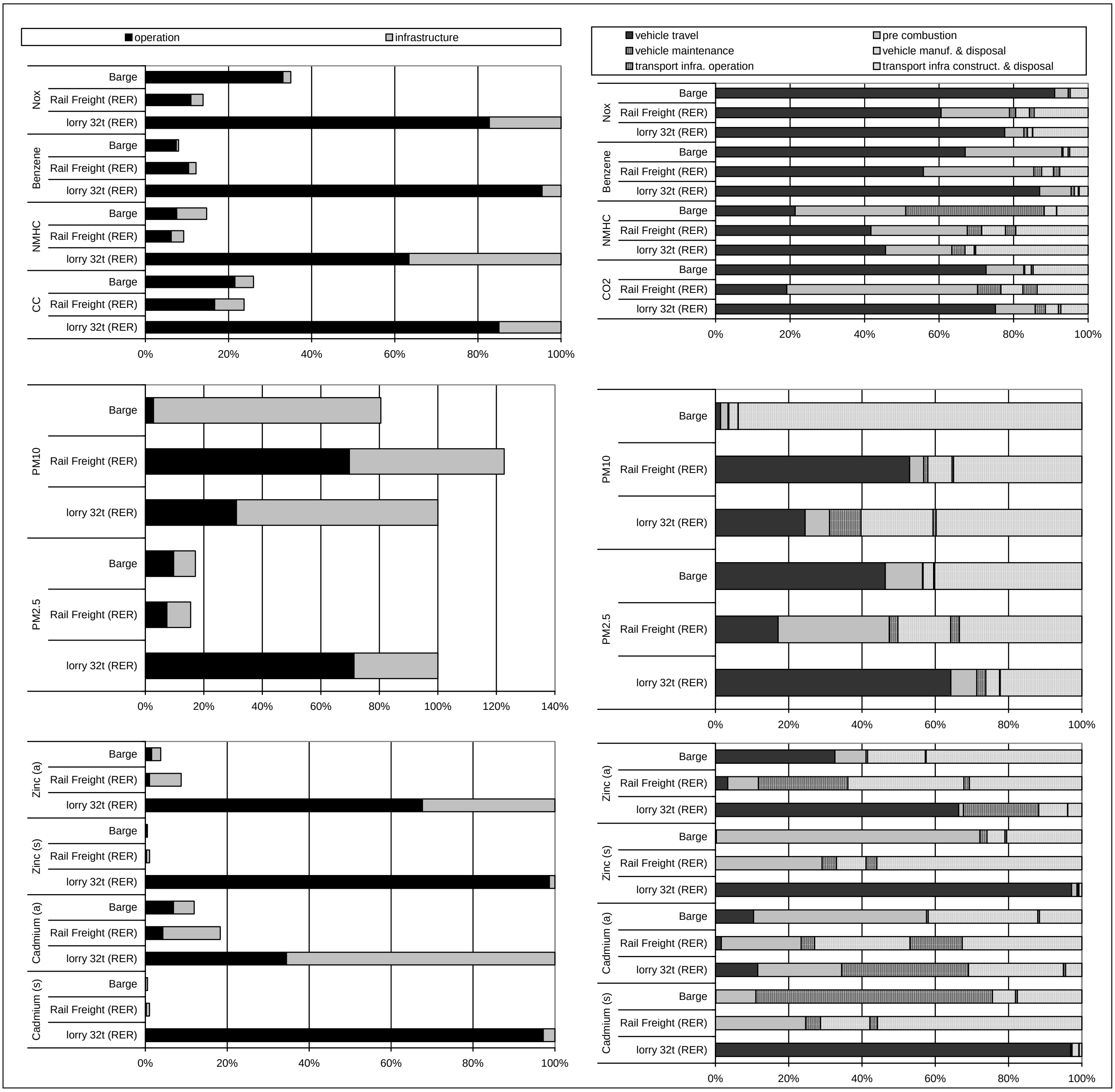

Fig. 4: Inter-modal comparison. Normalised values, 32 t lorry:= 100% and dominance analysis per transport service (total transport service performance: = 100%) (CC: Climate Change; including emissions of CO_2; CH_4 and N_2O)

sions (65%–92% less emissions) than road transport. Furthermore, the dominance analysis reveals the importance of infrastructure processes for regulated traffic emissions. For instance, for road, rail, and inland waterway transport, infrastructure processes account for 40%, 30%, 50% of the overall NMHC emissions, respectively. However, for individual NMHC species, this may be different, as in the case of benzene emissions.

For particle emissions, we obtain a more diverse picture. PM2.5 emissions for water and rail transport are considerably lower than for road transport. The main source for PM2.5 emissions are combustion processes: vehicle travel (50% of inland waterways transport and 70% of road transport, including 6% abrasion emissions) and pre-combustion (30% for rail). For coarse particles, in contrast, rail transport scores are worse than those for road transport. The major source of coarse particle emissions for rail transport is vehicle travel, with contributions from abrasion processes accounting for almost all emissions (99.5%). Coarse particle emissions from road transport due to vehicle travel are less dominant (25%) and also show a lower share of abrasion (64%). Coarse particle from barge transport emissions are dominated by infrastructure construction.

Of the various heavy metal emissions modelled in ecoinvent, zinc and cadmium are illustrated in this paper. As far as emissions of zinc and cadmium to soil are concerned, water and rail transport produce less than 1% of the emissions resulting from road transport for either pollutant. The dominant source for heavy metal soil emissions of road transport is tyre abrasion (zinc and cadmium contribute 1% and 0.001%, respectively, to the total tyre weight). Whilst the magnitude of vehicle travel emissions is in line with Maibach (1999), the remaining transport components score considerably lower, indicating lower heavy metal emissions in background processes, such as fuel pre-combustion. For rail transport, emissions to soil are dominated by infrastructure construction with significant contributions due to disposal. For emissions to air, road transport remains the option with the highest cumulative emissions; however, emissions of water and rail transport are in the range of 2 to 18%. Whilst vehicle travel is the dominating source for zinc emissions (with a 64% contribution of tyre abrasion to the total transport life cycle), vehicle travel is less important for overall cadmium emissions to air.

In terms of land use, water transport scores considerably worse than rail and road transport (see Fig. 5), and the life cycle is dominated almost exclusively by direct land use. The reason for this is the direct land occupation of artificial waterways with 7.19E-03 m^2a/tkm (occupation of natural waterways is not taken into account). Direct land use of rail (9.04E-04 m^2a/tkm) and road transport (1.00E-03 m^2a/tkm) contribute to about 50% of the life cycle. Indirect land occupation occurs for pre-combustion, infrastructure construction and disposal.

The dominance analysis of BOD scores reveals pre-combustion as the major source of BOD (90%) for inland waterway transport. A similar picture is obtained for road (70%) and rail transport (50%). In terms of absolute emissions, road transport shows considerably higher cumulative emissions than rail (10% of total road transport) and water transport (20% of total road transport). A considerable contribution of oil spills, classified as BOD in the dataset 'port operation', was not demonstrated.

3.3 Sensitivity Analysis

For the demand factor of infrastructure operation, a sensitivity analysis was performed by basing the demand factor on gross-tonne kilometric performance (d_5) instead of vehicle kilometre performance (d_6). This results in an increase of demand by a factor of 8 and 2 for the 32 t lorry and for rail transport, respectively. For the gaseous and particle emissions presented, the results reveal only slight sensitivity towards a change in the allocation method. For instance, we obtain an increase of less than 2% for PM2.5 for the entire life cycle. In contrast, land use exhibits greater sensitivity (**Fig. 5**). If we choose the Gtkm-performance as the allocation factor, the ranking changes and the scores for the 32t lorry then become considerably worse than those for the barge.

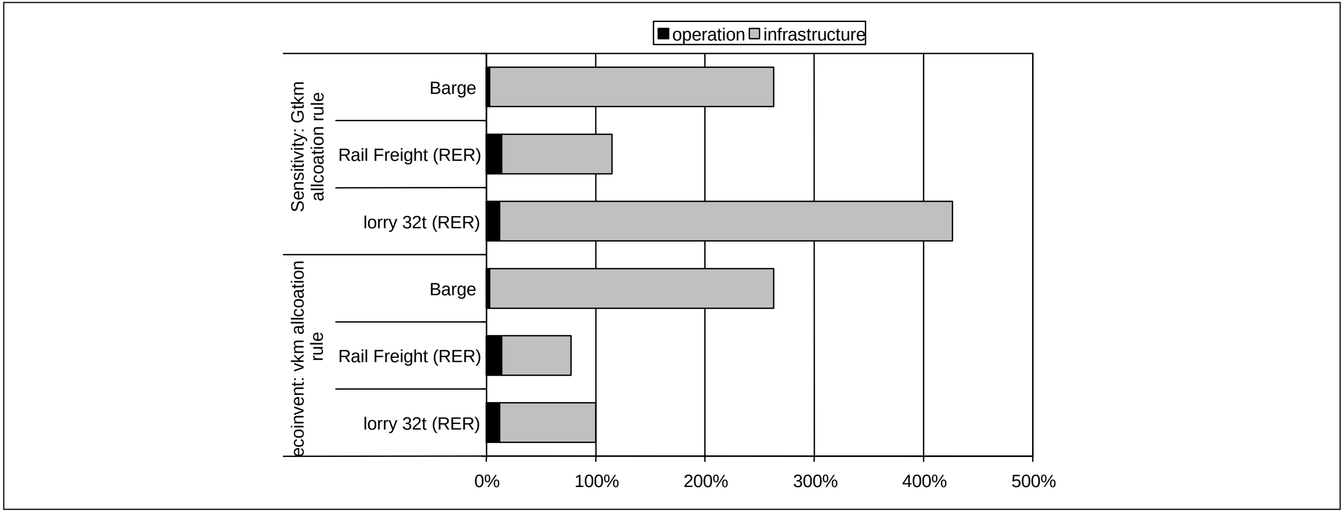

Fig. 5: Sensitivity Analysis of cumulative land occupation exchanges: Comparison of allocation rule. (Normalised value: 100%:= 32t lorry, allocation vkm performance)

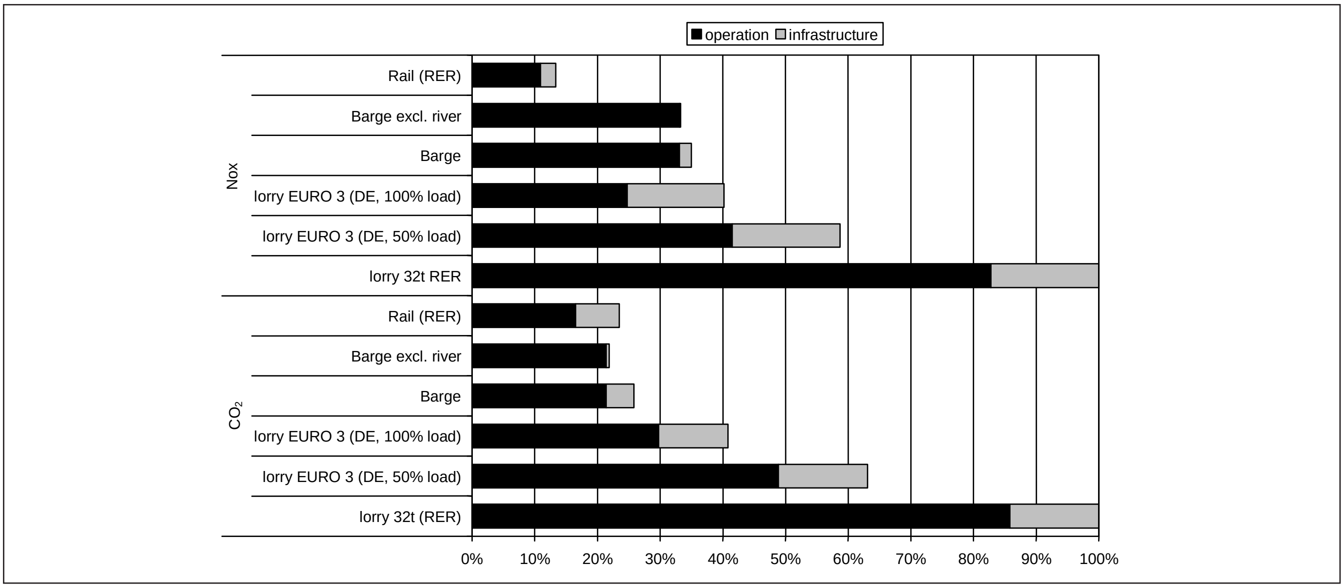

Fig. 6: Sensitivity Analysis of gaseous emissions: Alterations in operation parameters of road transport and barge infrastructure. (DE: regional code for Germany and RER: regional code Europe)

The results presented in the previous section are based on average operation and infrastructure characteristics. In the case of more specific transport comparisons, crucial assumptions such as load factor, traffic conditions, emission standards, the infrastructure used, the share of tunnels and bridges, etc., may influence the outcomes. In the following, we perform a brief sensitivity analysis by employing more specific data for road transport. The following alterations are made: vehicle operation represents average German motorway conditions and is performed by a EURO3 articulated lorry (34–40 t). Two different load factors are assumed: 50% and 100% (i.e. full return trip). For the latter, the total transport lifetime performance is considered twice as high as for the average lorry. The operation data are based on Keller (2004) and the results are documented in **Fig. 6**. Furthermore, we modelled water transport, excluding the environmental exchanges due to the construction and operation of artificial waterways.

For cumulative emissions of CO_2 and NO_X, we obtain a similar reduction compared with the average European 32 t lorry (40% and 60% for a load factor of 50 and 100%, respectively). However, while the CO_2 operation figures are still higher than for rail and water transport, operation figures of the 100% loaded lorry for NO_x are lower than those of barge transport. Due to the considerably higher NO_x emissions occurring in infrastructure processes (mainly transport infrastructure construction), road transport shows higher cumulative emissions than the barge and the ranking remains the same. The twice as large lifetime performance results in an approximate 25% reduction of the infrastructure emissions as far as cumulative emissions of CO_2 are concerned. In contrast, cumulative emissions of NO_x show no sensitivity. The reason for this difference is that cumulative CO_2 infrastructure emissions are based on both vehicle and transport infrastructure components, whilst cumulative NO_x emissions are dominated by transport infrastructure components. Finally, the exclusion of artificial waterways results in a considerable reduction of infrastructure scores which, however, only have a minor impact on the total life cycle score.

4 Conclusions, Recommendations and Perspectives

Transport datasets provided in ecoinvent Data v1.1 are primarily designed to provide background data for straightforward application in a variety of life cycle studies. The supply of generic transport datasets helps to avoid additional uncertainties due to the incorrect selection and application of highly specific transport data in situations where no such detailed information is readily available or required. Seen in this light, the provided datasets allow for a preliminary screening of the importance of transport processes within a product life cycle.

The inter-modal comparison has revealed considerable differences between transport modes, in particular between lorry transport and rail transport. Thus, in the absence of information about the mode of transport, we strongly recommend the user of transport datasets to employ the standard modes of transport as available for bulk materials (Frischknecht et al. 2004) so as to guarantee consistency and transparency.

With respect to transport-focussed LCAs, the results demonstrate the importance of infrastructure processes and, hence, indicate the importance of life cycle modelling for the assessment of conventional transport services. This is particularly true if we consider that, due to the introduction of new engines and emission reduction technologies, direct emissions will become less dominant, as demonstrated in the sensitivity analysis of lorry transport. The revealed reduction of emissions of up to 60%, compared with an average lorry operating in the reference year 2000, indicates that the presented generic datasets may have to be replaced with more specific data for transport-focussed LCAs. In either case, whether transport processes are identified as sensitive for the overall outcome of a certain product life cycle or for transport specific comparisons, the modular model structure and transparent documentation of demand factors allows for an easy and transparent integration of more case-specific data for the selected transport components.

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Food Purchases: Impacts from the Consumers' Point of View Investigated with a Modular LCA

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Abstract. The goal of this research work was to assist consumers in considering environmental aspects of food consumption. A simplified, modular LCA approach has been used to evaluate the impacts from the consumers' point of view. Comparative LCAs have been calculated for five single aspects of decisions: type of agricultural practice, origin, packaging material, type of preservation, and consumption. The inventory for one module includes the environmental impacts related to one particular product characteristic. The modular LCA allows one to investigate the trade-offs among different decision parameters. It could be shown that most of the decision parameters might have an influence on the overall impact of a vegetable product. Greenhouse production and vegetables transported by air cause the highest surplus environmental impact. For meat products, the agricultural production determines the overall environmental impact. The total impact for vegetable or meat purchases may vary by a factor of eight or two-and-a-half. Different suggestions for consumers have been ranked according to the variation of average impacts, due to a marginal change of behaviour. Avoiding air-transported food products leads to the highest decrease of environmental impacts.

Keywords: Consumers point of view; consumption patterns; decision-making, levels; eco-indicator 95; food, consumption; functional unit, food; marginal change; meat; modular, LCA; LCA, modular; LCA, simplified; purchase; vegetable