Global road transport's emission inventory for the year 2000

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ABSTRACT: Emission inventories are needed to determine the impact of different sectors and trace species on environment and health. We have calculated a highly differentiated emission inventory for road passenger and freight transportation worldwide, with a resolution of 1°x1° longitude/latitude, for CO_2, CO, NMVOC, CH_4, NO_x, primary PM and SO_2. Our bottom-up country by country calculation agrees to 2% with global fuel sales. We compare our results to other inventories, which have used a less differentiated approach or only cover certain world regions.

1 INTRODUCTION

Atmospheric research needs emission inventories to determine the impact of different sectors and trace species on the atmospheric composition and consequently on environmental and health impacts, among others climate change. Transportation has received increasing attention because it contributes about 15 to 20% of global anthropogenic emissions of carbon dioxide, carbon monoxide, nitrogen oxides, volatile organic hydrocarbons and primary particulate matter (EDGAR 32FT2000 Emission data, 2005). Furthermore, road transportation runs almost exclusively on oil products and combustion engines. With high growth rates for the transport volume in most parts of the world it is set to stay a major emitter of atmospheric pollutants, even if exhaust emission standards become more tightened and fuel quality improves.

This paper presents an inventory of road transport's fuel consumption and emissions of air pollutants on a 1°x1° grid for the whole world for the year 2000. We differentiate by vehicle category and fuel type on a country by country level. With this differentiation and scope of pollutants we go substantially beyond current knowledge (EDGAR 32FT2000 Emission data, 2005; Olivier et al., 2002; Schafer and Victor, 1999). Such a technology based approach is necessary for a more accurate estimate of current pollutant emissions.

Section 2 summarizes system boundaries and explains our calculation method, section 3 discusses validation, section 4 presents the emission results, and section 5 gives conclusions.

2 APPROACH

For the purposes of this inventory, road transport is any movement with motorized vehicles on public roads, for passenger or freight transportation. Excluded are movements by agricultural, forestry, building or construction machinery and with sports, pleasure or museum vehicles. Road vehicles are split up in five categories: mopeds, motor-cycles and three-wheelers (later referred to simply as two-wheelers); passenger cars; busses and coaches (later referred to simply as busses); light duty trucks below 3.5 tons gross weight; heavy duty trucks above 3.5 tons gross weight.

We consider consumption of motor gasoline, diesel, ethanol, biodiesel, LPG and CNG (the last four only for cars). We calculate exhaust emissions of CO_2 (from fossil fuels and non-fossil fuels separately), CO, NMVOC, CH_4, NO_x, primary PM and SO_2. Not included are evaporative losses, brake, tyre or clutch wear, resuspension, or discharges during maintenance, accidents or at the end-of-life.

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All emissions and the fuel consumption are calculated separately for 216 countries and territories, which are grouped in twelve world regions. For each country and vehicle-fuel combination, transport volumes (expressed as vehicle-kilometers) were estimated as described in Vanhove and Franckx (2006) and Borken et al. (submitted). Specific fuel consumption and exhaust emission factors (in g emitted substance per vehicle-kilometer) were estimated for each world region (Merétei, 2006; Borken et al., submitted). The sum-product of specific fuel consumption and transport volumes gives the total fuel consumption in a region. This calculated fuel consumption is compared to fuel sales data in road transport (IEA/OECD, 2003). The comparison is made separately for gasoline and diesel in each world region. Comparing on the level of world regions instead of countries has the advantage that fuel tourism does not distort the picture.

Our transport volumes are scaled such that the resulting fuel consumption matches the fuel sales data. Emissions are then calculated as the product of emission factor and transport volume, per vehicle-fuel combination and country.

2.1 *Uncertainties*

Emission factors have a high uncertainty even for OECD countries. This is because of the large number of factors influencing emissions, about which little data are available. Emission regulations provide some help, but they vary even between countries belonging to the same world region. Measurement data are often not representative of the fleet average. Also, so-called super-emitters have a high share in the overall emissions, despite their small number, and little data are available on them.

Inaccuracies in the mileage distribution over vehicle types affect both the overall level of emissions and the relative amount of particular substances. Especially uncertain is the distribution of freight vehicle mileage over light duty trucks and heavy duty trucks, as often only total ton-kilometers are given in statistics.

It is also known that some fuel is misallocated in the IEA data (e.g. fuel consumed in road transport is reported as fuel consumed in agriculture), notably in non-OECD countries. After comparison with other sources, we assumed different fuel sales for road transport than IEA in China, South Korea and India. This uncertainty affects the overall level of emissions in the respective world region.

3 VALIDATION

3.1 *Comparison of calculated fuel consumption with fuel sales data*

A first plausibility check for transport volumes, fuel consumption factors and fuel sales data is given by the comparison of our calculated fuel consumption with the fuel sales data (mostly IEA data). Globally, they are in good agreement; the total calculated gasoline consumption is lower than the sales data by 3% and the total calculated diesel consumption by 1%. In individual world regions, the discrepancy is sometimes much higher, but usually where gasoline consumption is underestimated, diesel consumption is overestimated, which means the discrepancy of total fuel sales is lower and the problem is partly due to difficulties with the distribution of mileage over fuel types (probably mostly freight mileage). The notable exception is the Middle East, where we underestimate both gasoline and diesel consumption by more than 40% compared to IEA sales data. We are therefore in the process of revising our transport volumes for this region and have also identified problems with the IEA sales data.

As discussed above, our raw data are adjusted according to the fuel sales data for each region and fuel separately. The following presents adjusted data only.

3.2 *Comparison with global and regional emission inventories*

As measurements of real world emissions are so far limited either in driving conditions or in the representativeness of the fleet, our best possibility of comparison are other global or regional emission inventories. Here we compare road transport's emissions globally, for North America, Western Europe and Asia. Comparison data are taken from one global, but regionally disaggregated inventory (EDGAR 32FT2000 Emission data, 2005) and one region specific inventory each (National Transportation Statistics 2004, 2005; De Ceuster et al., 2006; RAINS ASIA, 2001).

Table 1. Comparison of inventory data for road transport's emissions in the year 2000 globally, in North America, Western Europe and Asia; percentages denote differences to this work.

	CO_2 [Mt]	CO [Mt]	VOC [Mt]	NO_x [Mt]	PM [Mt]	SO_2 [Mt]
World						
this work	4223	111	15.6 [1]	29.2	1.33	1.79
EDGAR	4276 [+1%]	186 [+68%]	35.4 [+127%]	28.5 [-2%]		3.66 [+104%]
North America						
this work	1570	41	4.0 [1]	7.9	0.18	0.19
EDGAR	1639 [+4%]	64 [+56%]	8.4 [+110%]	7.5 [-5%]		0.33 [+74%]
NTS (only USA)	1407 [-10%] [2]	62 [+51%]	4.8 [+20%]	7.6 [-4%]	0.21 [+17%] [3]	0.24 [+26%]
Western Europe						
this work	800	12	1.7 [1]	5.4	0.28	0.09
EDGAR	819 [+2%]	17 [+42%]	4.4 [+159%]	4.6 [-15%]		0.27 [+200%]
TREMOVE	842 [+5%]	21 [+75%]	3.7 [+118%]	4.4 [-19%]	0.20 [-29%]	0.10 [+11%]
Asia						
this work	608	21	4.7 [1]	6.2	0.45	0.53
EDGAR	589 [-3%]	37 [+76%]	9.4 [+100%]	5.6 [-10%]		1.53 [+189%]
RAINS ASIA						0.78 [+47%]

[1] without evaporative emissions
[2] derived from fuel consumption
[3] PM_{10} ($PM_{2.5}$: 0.15 Mt)

The variation is small for CO_2 emissions, which means that the assumptions for road transport's fuel consumption are in close agreement. Therefore, differences in the other pollutants must result from different fleet average emission factors, i.e. due to different assumptions about the shares of the various vehicle-fuel combinations and the respective vehicle emission factors. E.g. EDGAR 32FT2000 values are calculated with emission factors for the year 1995. These do not capture the subsequent reductions in specific vehicle emissions and hence EDGAR has higher total emissions throughout than our work. One notable exception is the emission factor for NO_x: It has recently been discovered in EU15 that real world emissions from heavy duty vehicles are about 30% higher than the limit values (Hausberger et. al, 2003). This is already reflected in our emission factors, contrary to all other data.

Concerning VOC emissions it must be noted that we calculated tail pipe emissions only, and therefore our data are not directly comparable to other inventories which include evaporative emissions as well.

4 RESULTS

4.1 *Total global and regional pollutant emissions from road transport*

Road transportation emits about 4223 Mt CO_2, 111 Mt CO, 15 Mt NMVOC, 0.8 Mt CH_4, 29 Mt NO_x, 1.33 Mt primary PM and 1.8 Mt SO_2 worldwide in the year 2000 (Table 2).

The OECD regions (North America, Western Europe, Japan, Oceania) emit almost two-thirds of fossil CO_2, more than half of which is from North America. Asia and the Middle East account for one fifth of CO_2 emissions. Road transportation in the Former Soviet Union and in Central and Eastern Europe accounts for about 5% of CO_2 emissions, while Africa's share is about 3%. This reflects the regional shares in fuel consumption.

The shares are different for the other exhaust gases due to the regional differences in the vehicle fleet composition, fuel usages, in exhaust emission controls and technology: The OECD regions, which have started to implement vehicle exhaust emission controls long before the year 2000, account for 54% of CO, 41% of NMVOC, 38% of CH_4, 52% of NO_x, 39% of primary PM and only 18% of SO_2 emissions globally, with the US again providing the lion's share except for PM. Vice versa, all Asian regions have higher shares of exhaust pollutants than their respective share in fuel consumption. There, an exhaust emission control began only recently and many two-wheelers were still powered by two-stroke engines. Due to the high sulphur contents in their fuels, Africa, Latin America and the Middle East account for about half of global sulphur dioxide emissions.

Table 2. Emissions from road transportation in the year 2000 differentiated by region, in decreasing order of fuel consumption and CO_2 emissions, in absolute numbers and as shares of the global total.

	Fuel [Mtoe]	CO_2 [Mt]	CO [Mt]	NMVOC [Mt]	CH_4 [Mt]	NO_x [Mt]	PM [Mt]	SO_2 [Mt]
NAM	533 [37%]	1570 [37%]	40.9 [37%]	3.85 [26%]	0.18 [23%]	7.87 [27%]	0.18 [14%]	0.19 [11%]
EU15	268 [19%]	800 [19%]	12.2 [11%]	1.66 [11%]	0.08 [10%]	5.35 [18%]	0.28 [21%]	0.09 [5%]
LAM	130 [9%]	369 [9%]	9.3 [8%]	1.16 [8%]	0.06 [8%]	2.89 [10%]	0.13 [10%]	0.46 [26%]
EAS	101 [7%]	301 [7%]	10.1 [9%]	1.85 [12%]	0.11 [14%]	2.81 [10%]	0.15 [11%]	0.15 [8%]
JPN	78 [5%]	233 [6%]	4.6 [4%]	0.47 [3%]	0.03 [4%]	1.53 [5%]	0.04 [3%]	0.02 [1%]
MEA	71 [5%]	211 [5%]	8.5 [8%]	1.33 [9%]	0.07 [9%]	1.95 [7%]	0.10 [8%]	0.22 [12%]
SEA	59 [4%]	175 [4%]	7.1 [6%]	1.39 [9%]	0.08 [10%]	1.68 [6%]	0.15 [11%]	0.21 [12%]
CIS	47 [3%]	140 [3%]	6.6 [6%]	0.92 [6%]	0.04 [5%]	1.15 [4%]	0.06 [5%]	0.05 [3%]
AFR	44 [3%]	131 [3%]	3.3 [3%]	0.48 [3%]	0.02 [3%]	1.01 [3%]	0.05 [4%]	0.19 [11%]
SAS	43 [3%]	131 [3%]	4.0 [4%]	1.19 [8%]	0.08 [10%]	1.75 [6%]	0.14 [11%]	0.17 [9%]
CEC	29 [2%]	87 [2%]	2.2 [2%]	0.34 [2%]	0.02 [3%]	0.71 [2%]	0.03 [2%]	0.02 [1%]
OCN	25 [2%]	73 [2%]	2.2 [2%]	0.22 [1%]	0.01 [1%]	0.53 [2%]	0.01 [1%]	0.02 [1%]
World	1429	4223	110.9	14.86	0.78	29.23	1.33	1.79

NAM: North America; EU15: Western Europe; LAM: Latin America; EAS: East Asia; JPN: Japan; MEA: Middle East; SEA: South East Asia; SAS: South Asia; CIS: Commonwealth of Independent States; AFR: Africa; CEC: Central and Eastern Europe; OCN: Oceania

4.2 *Gridded pollutant emissions from road transport*

Emissions are distributed from a country level to a 1°x1° grid using rural and urban population densities, which are available for 1990 from EDGAR (Olivier et al., 2002). Depending on the vehicle category and world region, urban and rural populations are weighted differently in the gridding. The emissions of every vehicle category are split in two shares: one is distributed according to the density of the rural population, the other according to the density of the urban population. The shares are detailed in Table 3. This approach is a better approximation than distributing the traffic volumes according to the total population, because it takes into account the differences in the transport structure of rural and urban areas, e.g. individual motorized passenger transport in developing countries is available primarily in urban areas and heavy duty trucks drive more in rural areas compared to light duty trucks.

Figures 1 and 2 show as examples maps for emissions of CO_2 and NMVOC. Remarkable are especially the high NMVOC emissions in parts of India, China and South East Asia. These are due to the relatively low emission control standards and high share of two-wheelers, often still with two-stroke engines.

Table 3. Weighting of rural and urban population for gridding of emissions per vehicle category and region.

	Car		Bus		Two-wheelers		Light duty truck		Heavy duty truck	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
AFR+MEA	10%	90%	30%	70%	20%	80%	50%	50%	50%	50%
CEC	61%	39%	57%	43%	60%	40%	63%	37%	66%	34%
CIS	20%	80%	30%	70%	10%	90%	50%	50%	75%	25%
EAS+SAS+SEA	25%	75%	75%	25%	10%	90%	20%	80%	90%	10%
EU15+JPN	50%	50%	49%	51%	53%	47%	59%	41%	64%	36%
LAM	20%	80%	50%	50%	10%	90%	25%	75%	90%	10%
NAM+OCN	37%	63%	61%	39%	42%	58%	39%	61%	58%	42%

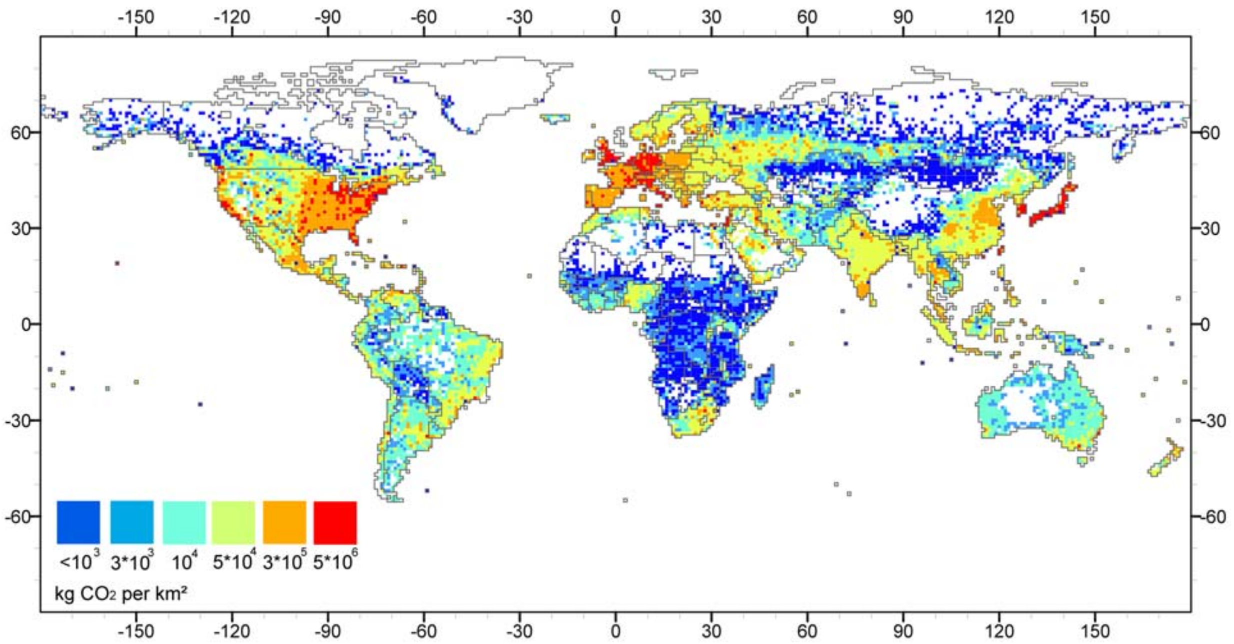

Figure 1. CO_2 emissions from road transportation in the year 2000

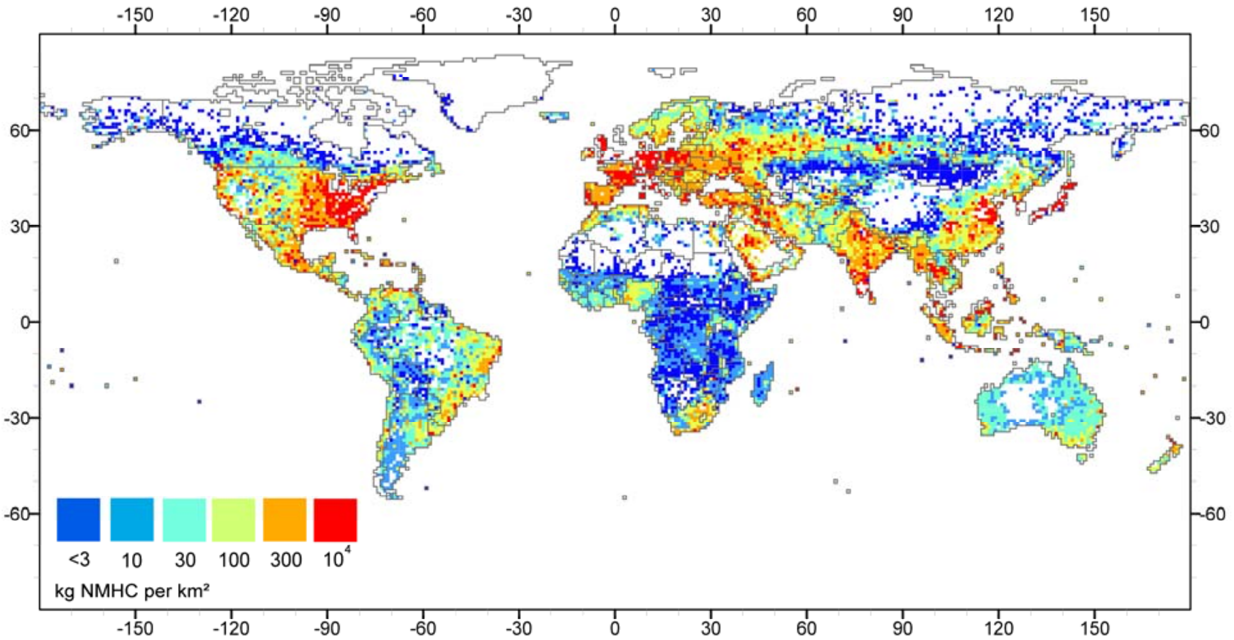

Figure 2. NMVOC emissions from road transportation in the year 2000

5 CONCLUSIONS

The work presented here is a major step towards a detailed and consistent global emission inventory for transportation (cf. QUANTIFY Homepage: http://www.pa.op.dlr.de/quantify/). Emissions of road passenger and freight transport are available separately, and if needed, emissions by vehicle category and by fuel type can be provided. Road transport's exhaust emissions have been calculated for the first time for many non-OECD regions at this level of detail. Fuel sales data have been cross-checked for some important non-OECD countries, which improves the reliability of the emission estimates for those countries.

The largest source of uncertainty remain the emission factors, especially in non-OECD regions. Also important are the uncertainties resulting from the lack of knowledge about the distribution of total ton-kms over the different vehicle and fuel types, and the associated load factors. A sensitivity analysis is planned to estimate the magnitude of the uncertainties. We also develop scenarios for future emissions from road transportation, analyzing the potential of different mitigation measures.

Similar inventories are being prepared for rail and inland waterways emissions. Together with the maritime shipping emission inventory produced by Det Norske Veritas and the aviation emission inventory produced by the Manchester Metropolitan University, the whole transport sector will be covered in much detail.

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