

GLOBAL AND COUNTRY INVENTORY OF ROAD PASSENGER AND FREIGHT TRANSPORTATION, THEIR FUEL CONSUMPTION AND THEIR EMISSIONS OF AIR POLLUTANTS IN THE YEAR 2000

Jens Borken*

German Aerospace Center (DLR) - Transportation Studies
Rutherfordstr. 2, 12489 Berlin, Germany
<http://www.dlr.de/vs>
Tel.: +49 30 67055-238, Fax: +49 30 67055-202
Jens.Borken@dlr.de

Heike Steller

German Aerospace Center (DLR) - Transportation Studies
Rutherfordstr. 2, 12489 Berlin, Germany
<http://www.dlr.de/vs>
Tel.: +49 30 67055-172, Fax: +49 30 67055-202
Heike.Steller@dlr.de

Tamás Merétei

Institute for Transport Sciences
H-1119 Budapest, Thán Károly u. 3-5., Hungary
<http://www.kti.hu>
Tel.: 36 1 3715848, Fax: 36 1 2055897
Meretei@kti.hu

Filip Vanhove

Transport & Mobility Leuven
Vital Decosterstraat 67A/0001, 3000 Leuven, Belgium
<http://www.tmleuven.be>
Tel.: +32 16 317735, Fax: +32 16 317739
Filip.Vanhove@tmleuven.be

* : *Corresponding author*

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Abstract

We present a comprehensive and validated inventory of road transport's emissions worldwide. Our bottom-up calculation matches to 2% and 10% with fuel sales data in OECD and non-OECD regions respectively, giving credibility. The inventory covers eight exhaust compounds emitted by five vehicle categories and five fuel types each. For many non-OECD countries road transport's exhaust emissions have been calculated for the first time at this level of detail. Furthermore, we have put forward a conservative estimate of primary PM emissions from diesel and gasoline vehicles.

The G7 countries together with Brazil, China, India, Mexico and Russia account for more than three quarters of all considered exhaust emissions, followed by major countries in the Middle East and South East Asia. Action in these fifteen countries could reduce emissions for the whole region significantly. Exhaust control and maintenance can focus on motorized two-wheelers, busses and heavy duty trucks.

The inventory is particularly suited for comparisons across countries and regions. Data uncertainties in transport volumes and real world emissions, notably of hydrocarbon and particulate matter should be reduced.

1. TRANSPORTATION EMISSIONS IN THE CONTEXT OF ATMOSPHERIC RESEARCH

Emission inventories are needed for the analysis of long-range transported air pollution and climate change. Such inventories must cover the relevant emissions at the scale of continents, be consistent across the different world regions and provide technical detail to analyze possible interventions. Global work has focused on transport's energy demand and carbon dioxide emissions (1), has treated road transportation as an aggregate (2; 3) or differentiated by road vehicle technologies and fuels on the level of world regions (4). Here we present an independent emission inventory for direct greenhouse gases and air pollutants from road transportation for all countries in the world with vehicle technology differentiated by five categories and five fuel types. The inventory is calibrated to the fuel balance in each country.

2. APPROACH

Definitions of world regions, vehicle categories and exhaust emissions considered

The inventory is set up for 216 countries and territories that are grouped to twelve world regions (TABLE 1). They are defined identically to (3) to be complementary with their non-transport emission data. For this inventory road transport is any movement with motorized vehicles on public roads, either for passenger or freight transportation. Road vehicles are differentiated by five vehicle categories using the respective UN-ECE classifications: Mopeds, motor-cycles and three-wheelers (L1, L3); passenger cars (M1); busses and coaches (M2, M3); light duty trucks below 3.5 tons gross weight (N1); and heavy duty trucks above 3.5 tons gross weight (N2, N3). We do neither include transport in pipelines nor movements by agricultural, forestry, building or construction machinery nor with sports, pleasure or vintage vehicles.

We account for the fuel consumed for vehicle propulsion; emissions from aggregates with a separate fuel system e.g. for cooling/heating or loading, are not included. We distinguish between motor gasoline, diesel, LPG and CNG, biodiesel (fatty acid methyl ester) and ethanol (bioalcohol) as propulsion fuels.

We calculate tail-pipe mass exhaust emissions of CO₂, SO₂, CO, VOC, NMVOC, CH₄, NO_x and primary PM as defined in the relevant emission control regulations of the European Union, Japan and the USA (5; 6). Fuel consumption, transport volumes and the corresponding exhaust emissions are given as totals for the year 2000.

Transport volume calibrated to national fuel consumption

Road transport's fuel consumption and emissions are calculated as the product of vehicle mileage and emission factor for each of the eight compounds, summed over all five vehicle categories times five fuel types, in all 216 countries (7, 8 and below). However, detailed data on transport volumes and emission factors is usually only available for OECD countries; for most other countries we derived a comprehensive data set ourselves. This ensures the necessary consistency across regions and countries.

The total vehicle mileage and its shares per vehicle category and fuel combination are adjusted such that the calculated fuel consumption matches the fuel sales in each country. The mileage distribution over the vehicle categories determines the fleet average emission factor per vehicle category and fuel.

This calibration to the national fuel sales also accounts for the known discrepancy between test cycle and real world consumption. Furthermore, all consumers of road fuel, being represented by our categorization or not, are thus included according to their proportion in fuel sales. Their exhaust gas emissions are implicitly calculated with on-road fleet average emissions factors.

On fuel sales data

Fuel sales data are certainly the most accurate factor in this calculation. Countries and trade organizations have kept for long a record of production, consumption, im- and export of oil products, of resulting taxes, etc. Generally we use the fuel consumption data allocated to the category "road" by the International Energy Agency (9; 10) believed to be consistent across countries. For the highest consuming countries we cross-checked with both, the respective national energy balance and a

detailed bottom-up calculation using national vehicle stock data, estimates of annual vehicle mileage and average fuel economy. Thus, the fuel consumption data for Argentina, Brazil, Hong Kong, Iran, Israel, Japan, the Republic of Korea, Mexico, Russia, Taiwan, Turkey, the US and Western Europe have been verified.

However in China, India and Iran we followed our bottom-up calculation and national data; we assume a consumption of diesel fuel of 26 Mtoe (11), 25.5 Mtoe (12) and 6 Mtoe in these countries instead of 12 Mtoe, 21 or 32 Mtoe and 12 Mtoe respectively (9; 10). IEA does not list the diesel fuel consumption for road transportation notably in the Former Soviet Union (most importantly Ukraine), the Middle East (Saudi-Arabia, Syria), Northern Africa (Algeria, Morocco) or for New Zealand. In these countries we use either national data, our own bottom-up calculation or we assume that 80% ($\pm 20\%$) of IEA's total final diesel consumption ('non specified') is to be allocated to road transportation. In total we have thus estimated an additional 27 Mtoe diesel fuel to be used in these countries. On the global scale, these corrections represent only 6% of the total registered road diesel fuel sales (9; 10). Yet for CIS and EAS we thus estimated the actual road diesel fuel consumption to be by more than 50% higher than reported fuel sales and by about 30% for AFR and MEA. This constitutes a significant uncertainty. For biofuels we use national data (13).

Fuel tourism or fuel bunkering is considered irrelevant on our global scale: The geographic location and time of final consumption are only shifted by a few hundred kilometers and maximum some months. Leakages, accidents, evaporation or misuse are unknown and believed to be negligible.

Transport volumes per country

Transport volume data for all countries are collected from national statistics or data bases by preference, particularly for CEC, WEU and the US (14; 15). The total mileage and its distribution over vehicle categories and fuel types for CIS, EAS, JPN, LAM, MEA and SAS result from the detailed bottom-up calculation for their key countries also used for the cross-check with the fuel balance. Their vehicle stock data is taken from (16) or national statistics. The regions thus treated in detail account for about 90% of the global road fuel consumption in the year 2000 (9; 10). For the remaining regions AFR, OCN and SEA we assumed mileage distributions per vehicle category and fuel type according to (4). For countries with missing data the average transport volumes per capita were transferred from neighboring countries in the same region.

We checked that the implied average annual transport volume per capita, per gross domestic product and per vehicle is plausible for each country compared to the respective region's average and across the regions. For instance, we reproduce that vehicle- and ton-kilometers per capita are by far highest in the OECD regions (3650-6600 tkm/cap and 4100-6600 car-km/cap), CEC, CIS, LAM and MEA form a middle group (850-1750 tkm/cap and 700-1700 car-km/cap) and AFR and the Asian regions are at the bottom (250-740 tkm/cap and 40-300 car-km/cap). Extreme outliers were replaced with regional average values.

This is the first global data base on a country by country level differentiated into passenger and freight transport by vehicle categories and fuel types and - most importantly - where transport volumes are validated by fuel consumption and fuel sales data. It is both input data for the subsequent calculation of exhaust emissions and a major result. A few observations for the year 2000 must suffice (TABLE 2): More than half of the global mileage of mopeds and motorcycles is driven in the Asian regions. Likewise, three quarters of bus mileage is driven in non-OECD countries. At an occupancy rate of 20 or (many) more passengers per kilometer, busses are by far the most important means for road passenger travel in these countries. On the contrary, and not as a surprise, cars are the most important passenger transport means in OECD countries. More than 80% of global mileage is driven there, with almost half in North America and Western Europe, each. Heavy duty trucks are in all regions the backbone of road freight transportation; their global transport volume is distributed about 60% to 40% between OECD and non-OECD countries. Light duty trucks are most prominent in NAM but are popular in non-OECD regions as well.

Vehicle fuel efficiency and emission factors per region

The exhaust emissions of new vehicles are determined by the emission control technology, which in turn is a function of the respective legislation in force. With fleet turnover, these new vehicles penetrate the fleet, in part substituting older vehicles. A standard deterioration of the exhaust emission

control devices with age is assumed. The fleet average emission per vehicle category then depends on the relative mileage shares of older and new vehicles and their respective emission levels in each region. The emission factors are weighted averages of travel on urban roads, rural roads and motorways and their respective average speed. For North America and Western Europe we have used the national averages as given by the authoritative US-MOBILE 6.2 model and Handbook Emission Factors respectively (17; 18).

For the other world regions we transferred the same methodology (18; 19) assuming an average driving speed of 50 km/h, half from slower urban and half from faster extra-urban driving. The emission factors are weighted averages according to the fleet composition (16) and the emission regulations (5; 6). The plausibility of our emission factors (TABLE 3) has been checked against the emission limit values that were in force in the 1990's, i.e. the years of production of the fleet driving in the year 2000 in the respective world region.

For carbon dioxide and sulphur dioxide emissions we assume complete combustion of the carbon and sulphur contained in the fuels. We assume a carbon contents of 86% of the fuels globally. In regions with biofuel use the respective percentage of regenerative carbon is subtracted when calculating the resulting total CO₂ emissions. The sulphur contents of the fuels is given as average over the regions in the year 2000 (TABLE 4). Emission factors per energy unit for LPG, CNG and bioalcohols were set equal to gasoline emission factors; biodiesel emission factors were set equal to diesel emission factor. As their share of global road fuel consumption is less than 0.5% in the year 2000 (9; 10), the uncertainties related to these simplifications are negligible. We assume the share of methane in emissions of volatile organic compounds for gasoline as 4-5% ±1% and for diesel as 3% ±1% in the different regions. Evaporative emissions of volatile organic compounds are not included in our data.

The PM emission factor refers to tail pipe emissions of primary particulate matter. Factors for gasoline powered vehicles are contentious and have been derived here for the first time globally. On the basis of the US-MOBILE 6.2 (17) and most recent European sources (25) we estimated the values given for OECD regions. As up to 90% of gasoline PM consists of unburnt hydrocarbons (25; 26) we scale with the VOC ratio per vehicle category to obtain PM emission factors for the other regions. For motor-cycles with two-stroke engines particularly, prevalent in the Asian region, we estimated an emission factor of 0.1 g/veh-km (25; 27). These values are considered a lower estimate. Neither abrasion from brake, tire or clutch wear nor suspension are included. However, most of the primary PM emissions is believed to be carbonaceous PM₁ or smaller and hence belongs to the chemical and size fraction most relevant for health and climate impacts (26).

3. VALIDATION AND UNCERTAINTIES

Validation with fuel sales data

Our calculated fuel consumption of 1408 Mtoe agrees to 1% with the corrected global fuel sales data for the year 2000 for each, gasoline and diesel (9; 10). More importantly, the calculated consumption matches for all OECD and non-OECD regions within 2% and 10% respectively. Only for AFR, OCN and SEA, the regions we have not treated in detail, our calculated value is by one third or 20 Mtoe too low. The calibration to national fuel sales data remains important to correctly reproduce the proportions in consumption between regions, between countries and across the different fuels. The following presents calibrated data only.

Comparison with global and regional emission inventories

There are no representative real world measurements to compare our emission estimates with. Therefore we compare with global or regional emission inventory data for road transportation (2; 4; 14; 15; 28; 29). This allows checking the mutual assumptions but does not allow to determine the validity of the results (TABLE 5).

All inventories concur for carbon dioxide emissions both globally and in the OECD regions. The slightly higher value of (2) for NAM cannot be confirmed by national (15) or international fuel data (9). Our higher values for Asia and the Reforming Region are due to our corrections of the fuel data as explained above. As all inventories use the same IEA data (9; 10) for the road fuel consumption any differences in the exhaust pollutants must result from different emission factors.

Notably EDGAR 32FT2000 values (2) are based on emission factors for the year 1995 that do only partially capture the subsequent reductions in vehicle exhaust emissions and hence (2) has higher total emissions throughout than our work.

Estimates for nitrogen oxide emissions agree within a few percent across the different inventories, both globally and in the regions. Our emission factors for OECD regions are slightly higher: It has recently been found that real world emissions from heavy duty vehicles in Western Europe are by about 30% higher than the limit values (30).

For carbon monoxide the emission estimates concur for the relative distribution among regions. However, absolute differences are large also. Compared to the more detailed emission inventories for the US and WEU (14; 15; 29) our emission factors seem low while the emission factors assumed by (4) appear rather high.

For sulphur dioxide emissions our lower totals reflect the reductions in the fuel sulphur contents since 1995, the base year of (2). The emissions of volatile organic compounds are not directly comparable: We calculated tail pipe emissions only, while the other inventories include evaporative emissions as well. Assuming that tail pipe emissions are on global average about one third of the total (31), our data are in $\pm 10\%$ agreement.

For PM emissions the large differences can be traced back to the emission factors assumed for gasoline vehicles. Our emissions factors broadly concur with (4) for diesel vehicles. For gasoline powered vehicles we assumed emissions about two orders of magnitude smaller (17; 25; 26), while (4) assumes as much as 40-50% of the respective value of diesel vehicles, without reference. This explains the difference in the resulting totals.

In the Asian region the differences for the various pollutant emissions should be carefully interpreted: First, the region has undergone a very rapid development in road transport volume and increase in vehicle stock. Therefore the state for the year 2000 is difficult to estimate. Second, vehicle exhaust emissions have not been as stringent and hence their variability is bigger than in OECD regions. Third, (4) caution themselves about the validity of their assumptions for non-OECD regions.

When analyzing each approach, its input data and assumptions, we can reasonably justify all differences. Given that two different estimates for the US (15; 29), each using an elaborate method, differ by about 10% for all compounds, the variability presented here should be perfectly acceptable for comparisons across world regions. Moreover, for non-OECD regions this is pioneering work and hence there is hardly anything to compare with.

Uncertainties

Three factors significantly influence the uncertainties of our approach: The fuel data used for calibration, the mileage distribution over vehicle categories and fuel types and finally the average emission factor per vehicle category and fuel type.

National fuel sales data are considered the most reliable. For OECD countries, that in total account for almost two thirds of the global road fuel consumption, we estimate the uncertainty in the order of 5%. However, from the validation of the national fuel data discussed in detail above we estimate the uncertainty notably for the diesel fuel data in AFR, CIS, EAS, MEA and SAS to be in the order of 30% to 50% and maybe half this value for gasoline. The global uncertainty in road fuel consumption would then be about 10% for gasoline and about 20% for diesel fuel.

The uncertainty in the mileage shares of each vehicle category is the more important the bigger the emission factors differ between them. Most relevant is the difference in emission factors between passenger cars and motorized two-wheelers for the Asian regions in the case of gasoline consumption. Per unit gasoline fuel the exhaust emissions from motorized two-wheelers are about a factor 3 to 5 higher for CO and a factor 7 to 12 higher for hydrocarbons. For light and heavy duty diesel vehicles the difference in PM and NO_x emissions per unit fuel consumption is a factor 5 to 6 and 7.5 to 9 respectively for the Asian region (cf. TABLE 3). We estimate that the uncertainty in total emissions due to uncertain mileage shares might be for each pollutant in the order of 30% in each region.

Third, calculating emissions factors by vehicle category for all world regions is a very audacious attempt so far been done only for several regions aggregated (2;3; 4). Our emission factors are based on the official certification procedures, assuming a reasonable maintenance. Therefore our estimates might be optimistic but they are consistent across regions and vehicle categories.

The various vehicle categories contribute differently to these uncertainties. We estimate that of all the emission factors for passenger cars are best known, followed by light duty trucks. Emissions from heavy duty trucks and busses are probably more uncertain, and data for motorized two-wheelers have probably the highest uncertainty, particularly for two stroke engines. Furthermore, the older the vehicle fleet or the less their maintenance, as in most developing countries, the higher is the variability in emissions and the bigger can be the influence of a few super-emitters.

4. RESULTS: EXHAUST EMISSIONS FROM ROAD TRANSPORTATION WORLDWIDE

Global and regional pollutant emissions from road transportation in the year 2000

Road transportation emits about $4280 * 10^6$ tons fossil carbon dioxide, $110 * 10^6$ tons carbon monoxide, $15 * 10^6$ tons non-methanous volatile organic compounds, $0.8 * 10^6$ tons methane, $30 * 10^6$ tons nitrogen oxides, $1.4 * 10^6$ tons primary particulate matter and $1.9 * 10^6$ tons sulphur dioxide worldwide in the year 2000. Gasoline fueled vehicles dominate total emissions of volatile organic compounds and carbon monoxide with 80% to 90% of the total, while diesel vehicles dominate emissions of nitrogen oxides, sulphur dioxide and primary particulates with 66%, 70% and 90% respectively (TABLE 6).

The OECD regions emit almost two-thirds of fossil CO₂, Asia and the Middle East account for less than one fifth of fuel consumption and CO₂ emissions. Central and South America emit a bit less than 10% of road transport's carbon dioxide. Road transportation in the Former Soviet Union and in Central and Eastern Europe accounts for about 5% of CO₂ emissions, a bit more than is emitted in Africa and Oceania together. This reflects the regional shares in fuel consumption.

The shares of the other exhaust gases vary with the vehicle fleet composition, fuel diesel shares, exhaust emission controls and technology respectively: The OECD countries, which have implemented vehicle exhaust emission controls long before the year 2000, account for about half the global CO and NO_x emissions, two fifths of VOC and primary PM and only one fifths of SO₂ emissions, with the US always 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. Many two-wheelers were there still powered by two-stroke engines. Due to the high sulphur contents, Africa, Latin America and the Middle East account for about half of global sulphur dioxide emissions.

Differentiation of emissions by vehicle category

We differentiate the pollutant emissions by vehicle category for two OECD and two Asian regions (FIGURE 1). North America, Western Europe, East Asia (i.e. Chinese region) and South Asia (i.e. the Indian region) together account for two-thirds of global road fuel consumption and CO₂ emissions, and for the majority of exhaust emission (except for SO₂ with 33%). Emissions from road transportation in NAM are roughly by a factor of two higher than in WEU. In Western Europe the high share of diesel fuel passenger cars is noticeable in higher primary PM emissions there, while the higher American share in gasoline fueled light duty vehicles and trucks drives the emissions of carbon monoxide. This high share of passenger cars is characteristic of industrialized countries. Passenger travel in North America means almost exclusively cars and light duty vehicles while in Western Europe mopeds, motorcycles, busses and coaches still have a small share in transport volume, fuel consumption and emissions.

In the Chinese and Indian regions, mopeds, two- and three-wheelers dominate the emissions of carbon monoxide and volatile organic compounds. This is a direct consequence of the high share of two-stroke engines, the lower quality fuel and less stringent exhaust emission control, all contributing to very high specific emissions. This is also true for the regions' busses and heavy duty trucks, resulting in pronounced shares in NO_x and PM emissions. The three to six times higher fuel sulphur contents results in sulphur dioxide emissions even higher than in the USA and WEU. In summary, each vehicle category is important for at least one pollutant in a certain region. Therefore this differentiation is necessary for a realistic estimate of the emissions and as a basis for any future scenario.

Highest and lowest emitting countries in road transportation

About three quarters of global exhaust emissions result from about fifteen countries only: These countries have high traffic volumes or old, unregulated, inefficient exhaust emission control, or both: The G7 countries (in order of decreasing CO₂ emissions: the United States, Japan, Germany, France, United Kingdom, Canada, Italy) figure among the top fifteen emitters for all pollutants covered here. Road transportation in the USA usually emits as much as in all other G7 states together. These OECD countries have economies with large trade flows and a lot of personal car travel; they account for 65% of the global GDP with a 10% share in population (32). Five big countries, China, Brazil, Russia, Mexico and India (in order of decreasing CO₂ emissions), are among places 2 to 12 for all pollutant emissions. They gather more than 40% of the global population and about 10% of global GDP (32). Each country accounts for 2% to 10% of global emissions from road transportation; they dominate their respective region's emissions. These countries typically have lower exhaust emission controls. Road freight transportation has a higher share in their pollutant emissions. Indonesia, Thailand and Taiwan have large numbers of mopeds and motorcycles, particularly with two-stroke-engines. They contribute strongly to global emissions of hydrocarbons, topping most OECD countries except the USA. In Iran and Saudi-Arabia petrol is so cheap that driving is abundant – often with outdated vehicles. Consequently these countries are likewise among the global top 15 emitters. In Oceania the top emitter – in road transportation – is Australia, the biggest emitting countries in Africa are South Africa, Egypt and Nigeria. These three countries alone account for more than half of the (corrected, see above) total road fuel consumption of the continent. Vice versa, the 150 countries and territories with lowest emissions from road transport account altogether for not more than 6% to the global totals, i.e. each for less than 0.04%. This group comprises countries with a small population, e.g. island states in Oceania or the Caribbean, but also Latvia, Bhutan and Greenland, and the poorest countries in Africa, Latin America or Asia.

5. DISCUSSION: COMPARISON WITH EMISSIONS FROM OTHER TRANSPORTATION MODES AND FROM OTHER ANTHROPOGENIC SOURCES

Compared to any other transport mode, road emissions are higher by one order of magnitude, with the notable exception of sulphur dioxide (TABLE 7): The sulphur contents in marine fuels is still two to three orders of magnitude higher with consequently high total exhaust emissions. For black carbon, it has been estimated that off-road machines emitted as much as 580 kt compared to 790 kt and 125 kt from diesel and gasoline on-road vehicles in the year 1996 globally (26).

Compared to all non-transport anthropogenic emissions, road transportation has a share of about 15% of carbon dioxide emissions in the year 2000; for carbon monoxide and nitrogen oxide emissions road accounts for 17% and 22% of the global total. In the USA, Western Europe and Japan road is however by far the single most important source sector for carbon monoxide emissions with about 70% and 50% shares respectively (2). There, where uncontrolled combustion is small road's share in nitrogen oxide emissions is with more than one third also much higher than their share in fuel consumption. Vice versa, the share of road transportation emissions for these two pollutants is below average in the Former Soviet Union, in the whole Asian region and in Africa. Emissions from power generation, operating with higher exhaust emissions, and biomass burning are more important sources there. The emission share for volatile organic compounds is globally around 10%, again higher in OECD countries.

6. CONCLUSIONS AND OUTLOOK

Our road transport emission inventory is a step towards a detailed and comprehensive global emission inventory for all transport modes (cf. 33). The match with the fuel balance in all important regions gives credibility to the calculated numbers. Road transport's exhaust emissions have been calculated for the first time for many non-OECD regions at this level of detail. Furthermore, we have put forward a conservative estimate of primary PM emissions from diesel and gasoline vehicles. Major uncertainties have been discussed.

Our inventory is consistent across countries and regions. Thus it is particularly suited for inter-comparisons to identify best practice examples, and opportunities for action, technology transfer, capacity building, environmental legislation, etc. We have identified the fifteen highest emitting

countries and relevant vehicle fleets (notably motorized two-wheelers and busses) for which dedicated actions could make a sizeable impact in reducing pollutant emission also for the whole region.

To reduce uncertainties further, emission measurements notably in highly dynamic developing countries are needed. Particular attention should be paid to hydrocarbon and particulate emissions as well as to the sulfur contents of the fuels. In addition it is necessary to determine the vehicle mileage more accurately. We will develop scenarios for future emissions from road transportation, analyzing the potential of different mitigation measures.

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TABLE 1 Region acronym and corresponding geographical scope

Region acronym	Geographic area
AFR	Africa (North and Sub-Saharan Africa)
CEC	Central and Eastern Europe including the Baltic States
CIS	Commonwealth of Independent States (Former Soviet Union excluding the Baltic states)
EAS	East Asia including the People's Republic of China and both Koreas, Hong Kong and Taiwan
WEU	Western Europe (WEU and EFTA countries)
JPN	Japan
LAM	Central and South America including Mexico and the Caribbean
MEA	The Middle East including Turkey, Israel, the Arab countries and Iran
NAM	North America (USA and Canada)
OCN	Oceania including Australia, New Zealand and Pacific island states
SAS	South Asia: the Indian subcontinent including Afghanistan, Bangladesh, Nepal and Pakistan
SEA	South East Asia including Indonesia, Malaysia, the Philippines, Thailand and Vietnam
<i>These groupings do not imply comments on the political or administrative status of a country or region.</i>	

TABLE 2 Road transport volumes in the year 2000 differentiated by region and vehicle category, in decreasing order of total road fuel consumption. Raw data before calibration with fuel consumption

Region	Moped & motorcycle		Passenger car		Bus		Light duty truck		Heavy duty truck	
	[10 ⁹ vkm]	[share]	[10 ⁹ vkm]	[share]	[10 ⁹ vkm]	[share]	[10 ⁹ vkm]	[share]	[10 ⁹ vkm]	[share]
NAM	16	1%	2471	32%	16	5%	1421 ^a	51%	427	31%
WEU	121	10%	2508	32%	34	12%	284	10%	265	19%
LAM	111	9%	590	8%	43	15%	329	12%	110	8%
EAS	297	24%	264	3%	38	13%	130	5%	152	11%
JPN	108	9%	510	7%	7	2%	180	6%	115	8%
MEA	98	8%	310	4%	16	5%	83	3%	87	6%
SEA	189	15%	149	2%	35	12%	104	4%	45	3%
SAS	172	14%	53	1%	27	9%	38	1%	74	5%
CIS	61	5%	180	2%	35	12%	74	3%	48	3%
AFR	37	3%	178	2%	27	9%	71	3%	28	2%
CEC	39	3%	242	3%	10	3%	23	1%	27	2%
OCN	3	0%	277	4%	4	1%	47	2%	17	1%
<i>World</i>	1252	100%	7732	100%	290	100%	2784	100%	1397	100%

a: Including SUVs, vans and pick-ups.

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

TABLE 3 Emission factors per vehicle category, fuel type and region for the year 2000

	FC	CO	HC	NOx	PM	FC	CO	HC	NOx	PM
	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]	[g/vkm]
	Passenger car - gasoline fueled					Passenger car - diesel fueled				
AFR	104	11.3	1.3	1.9	0.002	89	0.69	0.15	0.70	0.16
CEC	61	5.7	0.65	0.98	0.001	52	0.56	0.15	0.90	0.18
CIS	81	11.5	1.9	1.7	0.003	68	1.16	0.99	1.45	0.22
EAS	83	8.6	0.96	1.4	0.002	60	0.58	0.17	0.98	0.20
WEU	64	4.7	0.52	0.85	0.001	53	0.51	0.12	0.95	0.15
JPN	52	2.5	0.17	0.38	0.001	51	0.30	0.12	0.62	0.15
LAM	91	5.7	0.65	0.98	0.001	68	0.56	0.15	0.90	0.18
MEA	88	11.5	1.9	1.7	0.003	77	1.16	0.99	1.45	0.22
NAM	86	7.5	0.78	0.79	0.001	79	0.88	0.39	1.12	0.15
OCN	56	5.6	0.56	0.95	0.001	52	0.51	0.09	0.62	0.11
SAS	81	12.2	2.1	2.2	0.003	60	1.45	1.18	1.45	0.26
SEA	89	15.4	1.7	2.5	0.003	76	1.07	0.99	1.45	0.23
	Light duty truck - gasoline fueled					Light duty truck - diesel fueled				
AFR	156	24	1.9	2.9	0.004	133	1.2	0.33	1.2	0.37
CEC	101	21	1.2	2.3	0.002	86	0.9	0.20	1.3	0.26
CIS	103	28	2.4	3.0	0.006	94	1.5	1.28	4.8	0.29
EAS	113	22	1.7	2.7	0.003	92	1.0	0.65	4.3	0.28
WEU	101	17	1.1	1.6	0.002	85	0.7	0.17	1.1	0.22
JPN	96	12	0.6	1.3	0.002	85	0.4	0.20	0.9	0.20
LAM	89	21	1.2	2.3	0.002	85	0.9	0.20	1.3	0.26
MEA	103	28	2.4	3.0	0.006	94	1.5	1.28	4.8	0.29
NAM	103	13	1.1	0.9	0.002	98	1.1	0.50	1.1	0.17
OCN	83	18	1.4	2.3	0.002	87	0.8	0.16	1.1	0.21
SAS	-	-	-	-	-	100	1.5	1.41	4.8	0.34
SEA	138	28	2.4	3.2	0.006	107	2.0	1.28	1.8	0.63
	Heavy duty truck - gasoline fueled					Heavy duty truck - diesel fueled				
AFR	-	-	-	-	-	273	2.6	1.04	11.9	0.49
CEC	316	37.8	3.4	4.9	0.022	253	2.3	0.93	10.4	0.43
CIS	339	55	4.8	4.9	0.031	272	3.3	2.00	12.0	0.62
EAS	273	45	4	4	0.025	273	2.6	1.25	12.0	0.62
WEU	-	-	-	-	-	237	1.7	0.64	8.9	0.33
JPN	-	-	-	-	-	221	1.5	0.51	8.5	0.25
LAM	-	-	-	-	-	238	2.3	0.93	10.4	0.43
MEA	-	-	-	-	-	306	3.3	2.00	12.0	0.62
NAM	282	15.7	1.5	3.4	0.010	225	2.6	0.61	9.2	0.34
OCN	-	-	-	-	-	266	2.5	1.00	11.5	0.47
SAS	-	-	-	-	-	272	3.6	2.20	13.6	0.68
SEA	-	-	-	-	-	273	3.3	2.00	11.7	0.62
	Moped & motorcycle - gasoline fueled					Bus & coach - diesel fueled				
AFR	30	13.2	4.1	0.16	0.1	340	5.5	3.0	13.6	1.01
CEC	29	15.4	3.9	0.24	0.002	318	5.1	2.5	13.9	0.89
CIS	29	15.1	3.8	0.22	0.1	340	6.0	3.7	14.8	2.08
EAS	30	12.9	3.8	0.22	0.1	286	5.5	3.0	13.6	1.01
WEU	34	15.6	3.3	0.24	0.027	319	4.1	1.7	12.8	0.65
JPN	29	10.1	2.1	0.28	0.002	281	3.2	1.2	12.1	0.47
LAM	29	15.4	3.9	0.24	0.1	349	5.1	2.5	13.9	0.89
MEA	29	15.1	3.8	0.22	0.1	374	6.0	3.7	14.8	2.08
NAM	56	11.8	2.1	1.23	0.002	317	3.8	1.5	12.6	0.59
OCN	30	12.5	3.5	0.21	0.1	326	5.2	2.8	13.2	0.96
SAS	24	15.7	4.6	0.20	0.1	340	6.1	3.7	15.3	2.09
SEA	29	15.9	4.3	0.15	0.1	348	6.0	3.7	14.8	2.08

FC: Fuel consumption. vkm: Vehicle kilometres travelled.
 -: Vehicle/fuel combination not applicable (or negligible) in region.

TABLE 4 Sulphur contents of the motor fuels in the different regions assumed for the year 2000

Region	Gasoline [ppm S]	Diesel fuel [ppm S]	Reference
AFR	1000	4000	(20)
CEC	150	500	(21; 22)
CIS	400	1000	(21)
EAS	600	1000	(20)
WEU	100	250	(20)
JPN	35	350	(20)
LAM	1000	3000	(20)
MEA	800	3000	(20)
NAM	138	350	(20; 23; 24)
OCN	500	500	(21; 22)
SAS	1000	2250	(20)
SEA	800	2800	(20)

TABLE 5 Comparison of inventory data for road transport emissions in the year 2000 in different world regions

Region	Reference	CO ₂ [Mt]	NO _x [Mt]	CO [Mt]	SO ₂ [Mt]	NM VOC [Mt]	PM [Mt]
World	(2)	4276	28.5	186	3.66	33.8	-
World	(4)	4037	29.5	272	-	42.3	2.7
World	this work	4282	29.9	110	1.89	15.0 ^a	1.37
OECD	(2)	2776	14.1	89	1.02	14.8	-
OECD	(4)	2919	15.0	158.2	-	21.3	1.1
OECD	this work	2678	15.3	60	0.33	6.2 ^a	0.52
NAM	(2)	1639	7.5	64.1	0.33	8.0	-
NAM+	(4) incl. MEX	1611 ^e	7.7	97	-	12.6	0.54
NAM	this work	1566	7.8	40.8	0.19	3.8 ^a	0.18
USA	(15)	1407 ^c	7.6	62	0.24	4.8	0.15 ^d
USA	(29)	-	8.4	68	0.26	5.3	0.23
USA	this work	1449	7.2	38	0.17	3.6 ^a	0.17
WEU	(2)	819	4.6	16.6	0.27	4.2	-
WEU+	(4) incl. TUR	869	5.4	44.4	-	6.2	0.41
WEU	(14)	842	4.4	20.8	0.10	3.7	0.20 ^b
WEU	this work	800	5.4	12.1	0.092	1.6 ^a	0.28
ASIA	(2)	589	5.6	37	1.53	8.9	-
ASIA+	(4) incl. OCN	591	6.4	51.2	-	10.3	0.76
ASIA	(28)	-	-	-	0.8	-	-
ASIA	this work	608	6.2	21	0.53	4.4 ^a	0.44
REF	(2)	153	1.5	11	0.19	1.8	-
REF	this work	247	2.1	9	0.08	1.35 ^a	0.11
RoW	(2)	757	7.4	49	0.92	8.3	-
RoW	this work	750	6.2	20	0.96	3.7 ^a	0.30
Region proxies: OECD := WEU+JPN+NAM+OCN; ASIA := EAS+SAS+SEA; REF := CEC+CIS; RoW := AFR+LAM+MEA							
-: No data.							
a) Without evaporative emissions. b) From diesel fuelled vehicles only. c) Derived from fuel consumption.							
d) PM _{2.5} (PM ₁₀ : 0.21 Mt). e) About 1514 Mt CO ₂ without MEX, that accounts for about 6% of the total road fuel consumption in NAM+MEX.							

TABLE 6 Emissions from road transportation in the year 2000 differentiated by region, in decreasing order of fuel consumption and CO₂ emissions

	Fuel	CO ₂	CO	NMVOC	CH ₄	NO _x	PM ^a	SO ₂
Region	[Mtoe]	[Mt]	[Mt]	[Mt]	[Mt]	[Mt]	[Mt]	[Mt]
NAM	531	1566	40.8	3.84	0.180	7.81	0.18	0.19
WEU	268	800	12.1	1.64	0.078	5.37	0.28	0.092
LAM	133	379	9.3	1.21	0.066	2.94	0.14	0.47
EAS	101	301	10.3	1.86	0.109	2.80	0.15	0.15
JPN	78	233	4.62	0.47	0.030	1.53	0.039	0.024
MEA	75	224	7.46	1.33	0.067	2.09	0.10	0.26
SEA	59	175	7.14	1.39	0.075	1.68	0.15	0.21
CIS	54	160	6.74	1.00	0.048	1.41	0.084	0.061
AFR	49	146	3.44	0.53	0.024	1.17	0.061	0.23
SAS	43	131	3.81	1.14	0.078	1.76	0.14	0.17
CEC	29	87	2.19	0.34	0.019	0.71	0.029	0.017
OCN	27	79	2.19	0.22	0.010	0.59	0.017	0.025
World	1448	4282	110	15.0	0.78	29.9	1.37	1.89

a) PM from diesel and gasoline fueled vehicles (tail-pipe).

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

TABLE 7 Global pollutant emissions from different transport modes and from non-transport anthropogenic emissions in the year 2000

	CO ₂	CO	NMVOC	CH ₄	NO _x	SO ₂
Mode	Mt	Mt	Mt	Mt	Mt	Mt
Road (<i>this work</i>)	4'282	110	15.0 ^a	0.78	29.9	1.89
Rail & inland navigation	390	13	4.6	0.01	5.9	2
Aviation	654	1.8	0.6	0.01	2.3	0.2
Maritime shipping	428	0.1	0.02	0.03	9.6	7.3
Anthropogenic non-transport	24'166	876	147	-	80.4	137
<i>a: Without evaporative emissions.</i>						
Non-road data: (2)						

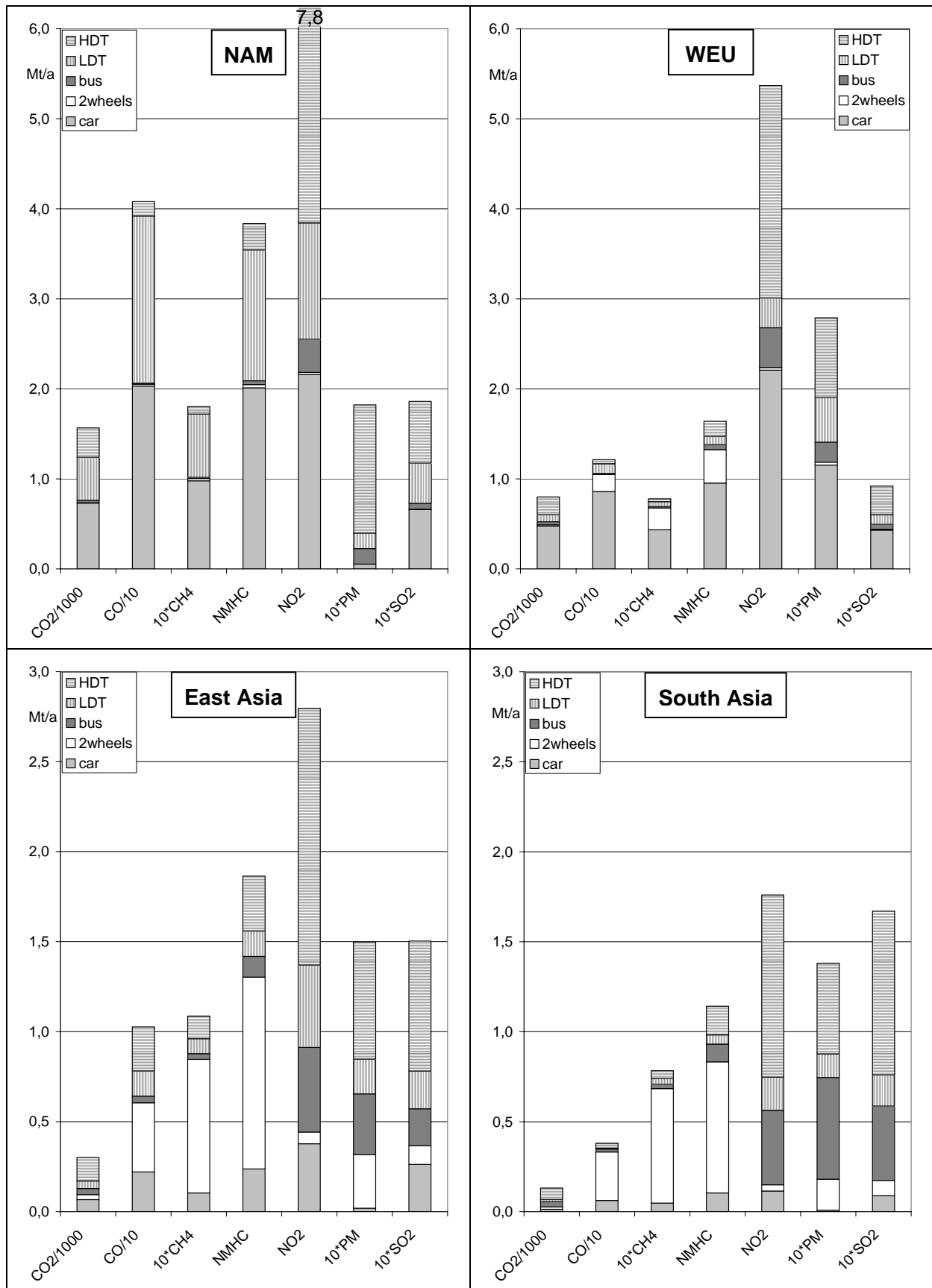


FIGURE 1: Road transportation's emissions of CO₂ and regulated pollutants in NAM, WEU, East and South Asia in the year 2000, differentiated by vehicle category. Scales adapted for each pollutant.