European road transport emission trends linked to policy developments

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ABSTRACT

The implementation of strict measures to control NO_x emissions from road transport is demonstrated here to be a main reason for the continued Western European emission reductions. The results indicate that even though the effectiveness of European standards (EURO 1-4) is hampered by a slow vehicle turnover, loopholes in the type-approval testing, and an increase in diesel consumption, the effect of such technical abatement measures is traceable in the evolution of European road traffic emissions over the last 15 years. Transport emissions increase in line with the growth in economy in large parts of Eastern Europe. As a result of the recent development in road transport emissions, the emission levels in Eastern and Western Europe are now rapidly approaching each other.

INTRODUCTION

The analysis of anthropogenic emission trends of nitrogen oxides (NO_x=NO+NO_2) is important in order to increase our understanding, hence our ability, to optimize abatement of air pollution and reduce the adverse effects of these pollutants on ecosystems, human health and climate, on local, regional and global scales. Emissions from road transport have been determining NO_x emission levels for decades. Already in 1970 the road transport emissions became the single most important source of NO_x emissions[1]. The environmental, climate and health effects of NO_x are well documented. Carslaw et al.[2] have for instance demonstrated the risk for the EU hourly limit of nitrogen dioxide (200µg/m3) not to be met by 2010 in European cities due to the recent developments in road transport. Further, Reis et al.[3] showed that road traffic may contribute substantially to exceedances of ozone indicators for both health and forests in Europe. Globally, road transport is responsible for substantial increase in the concentration of tropospheric ozone (5–15%) not only in the vicinity of the source but also in remote areas[4, 5].

Much effort has already been invested in order to abate NO_x emissions in Europe, both at national and at European-wide level. The first UNECE regulations to control emissions from motor vehicles (ECE-R15) were already being discussed in the 1950s and came into force in 1970[6, 7]. They were designed to reduce the emissions of carbon monoxide (CO) and hydrocarbons (HC) due to incomplete combustion. The early European legislation can be viewed as a response to the US initiatives, which had at that time already introduced air pollution control policies to address the degradation of air-quality in Los Angeles, California. Much later, and within the framework of the Convention of Long-range Transboundary Air Pollution (LRTAP), two Protocols regulating NO_x entered into force; the 1988 Sofia Protocol sets a limit to national annual emissions or transboundary flux of nitrogen oxides at the 1987 level, while the effect-based 1999Gothenburg Protocol sets fixed emission ceilings for the year 2010[8]. The EU National Emission Ceilings (NEC) Directive[9] defines slightly more ambitious2010 emission ceilings for some of the Member States than the Gothenburg Protocol. The reason for this is possibly that the NEC was designed to deliver slightly different environmental objectives compared to Gothenburg Protocol in terms of ecosystem protection. The European Commission has also issued a number of Directives and instruments aiming to control NO_x emissions from specific sectors. These are principally the Large Combustion Plant Directive (Directives 88/609/EEC and 2001/80/EC), emission limits for engines used in non-road mobile machinery (Directive97/68/EC), the Waste Incineration Directive (Directive2000/76/EC) and the ECE/Euro standards for road vehicles (Directive 70/220/EC and revisions). Still, half of the EU Member states report that they anticipate missing their NO_x ceilings under the NEC Directive[10].

This paper analyse trends in European road traffic emissions per country since 1980, and investigates to what extent the decrease in emissions after 1990 can be linked to policy regulations. The study relates NO_x emission trends in Europe to the evolution of fuel consumption as well as to the changes in vehicle technology.

DATA SOURCES AND QUALITY

The study relies mainly on emissions and activity data reported and reviewed under the EMEP (Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe) programme. The data are available from the online database, WebDab (www.ceip.at). The UNECE Emission Reporting Guidelines (www.unece.org/env/documents/2008/EB/EB/ECE.EB.AIR.97.pdf) and the EMEP/CORINAIR Guidebook (www.eea.europa.eu/publications/EMEPCORINAIR5) defines directions for the submissions. Specifically, the transport emissions should be reported according to fuel sold. The national submissions to the Convention on LRTAP are accompanied by an Informative Inventory Report documenting the uncertainties in the data included and possible deviations from the recommended methodologies in the Guidebook. In the absence of reported data, our analysis utilizes trends in fuel consumption and implied emission factors from the GAINS database (www.iiasa.ac.at/web-apps/apd/gains). EDGAR emission data (www.mnp.nl/edgar) are included for a few countries for which neither reported nor GAINS data are available. For the period 1980 to 1990, we include fuel consumption data from international statistics published by OECD and UNECE. The coverage of officially reported emissions is about 40% in the 1980s, increasing to nearly 60% after 1990. The level of confidence is anticipated to be higher for the reported and reviewed emission data, due to country specific insight and the detailed input to the calculations.

The uncertainty level for national inventories included in the EMEP inventory is considered to be between 8% and 23% for Western Europe and around 25% for Eastern Europe[1] after 1990. Schöpp et al.[11] indicate that the uncertainty in individual sectors might be nearly three times higher for emissions from gasoline passenger cars and diesel heavy duty trucks in line with results reported from Kuhlwein and Friedrich[12]. The EMEP emission trends have also been validated by recent model studies including measurements[13, 14] as well as a study applying inversion techniques with GOME and SCIAMACY measurements[15].

EUROPEAN ROAD TRANSPORT EMISSION TRENDS IN THE LAST TWENTY-FIVE YEARS

There are substantial differences in the emission trends depending on the socio-economic and political situation in individual European countries. Based on the developments in road transport, we have distinguished three emission trend regimes between 1980 and 2005.

A) 1980-1990

Road transport emissions in Europe increased by 13% in this period, despite a 10% reduction in Eastern Europe. The reduction in the east is linked to decreased fuel consumption due to income deterioration, as a consequence of the inefficiency in investments. A few exceptions to this general picture are not readily explained due to lack of data for individual Former Yugoslav and USSR countries. In Western Europe, road transport emissions increased by 27%. Fuel consumption went down or stabilized due to the high oil prices following the oil crisis in the 1970s. At the same time, early regulations to control CO and HC emissions introduced by different steps of UNECE Regulation No. 15 (1970-1983) were associated with increase in NO_x emissions from vehicles[7]. Taken the relatively slow fleet turnover into account, these regulations may well be responsible for the overall emission increases. Road transport emissions decreased in Sweden, Belgium, Luxembourg, Austria, Switzerland, Cyprus and Malta, possibly due to early introduction of diesel passenger cars.

B) 1990-2000

In this period, road transport emissions decreased by 23% in Europe, and reductions were evident (about 20%) both in the east and the west. In Eastern Europe, the decrease in emissions is associated with decreased consumption due to restructuring of the economies after the disruption of the Soviet Union in 1991. In some of these countries however, decreased emissions are linked to improved emission factors, rather than decreased fuel consumption. The share of the high-polluting car fleet built in Eastern Europe decreased there due to imports of cleaner cars from Western Europe. Increase in emissions due to increased consumption without an accompanying decrease in emission factors, are seen Albania and the Former Yugoslav Republic of Macedonia. In Western Europe, the introduction of improved vehicle technologies and stringent inspection systems related to the Euro standards was the primary force in reducing NO_x road traffic emissions, despite economic growth and increases in fuel consumption. Some countries increased their emissions due either to the high age of the vehicle fleet combined with increasing number of vehicles (Portugal, Spain and Greece), late introduction of Euro standards (Turkey, Cyprus and Malta) or “fuel tourism” (Austria, Ireland and Luxembourg). The latter is a term used for retail purchase of fuel in one country for consumption abroad, mainly due to fuel price differences.

C) 2000-2005

In this period road transport emissions in Europe continue to decrease. The total European emission reduction in this five years period is 11% comparable to the preceding regime, but with important differences in Eastern and Western Europe. Fuel consumption in the traffic sector increased in all European countries except in Germany. In Germany high tax on fuel combined with improvements in vehicle technology, result in a considerable decline in diesel consumption. Increase in emissions from Eastern Europe (16%) follows the increase in fuel consumption. The recovering of the economies is responsible for the emission growth. Many countries have their own car industry, so new western technologies will not necessarily become standard. In addition, lead additives which poison the catalysts, are not completely abandoned both due to lack of regulations and due to a claimed black market for leaded gasoline. Finally, the price of fuel is low and even subsidised in some countries[16]. In Belarus, emission decreased between 2000 and 2005 mainly because locally produced lorries comply with Euro 2 and later standards, and passenger cars are imported. The situation with respect to how the introduction of Euro standards has influenced the emission trend is mixed for the EU-10 countries. While Hungary, Latvia, Lithuania and Slovakia report an increase in emissions between 2000 and 2005, due to less effective implementation of the Euro Standards, decrease in emissions are seen in Poland, Czech Republic, Estonia and Slovenia. Croatia has implemented the Euro standards from year 2000 and decreased their emissions.

Contrasting the general increase in Eastern European emissions, the decrease in emission (22%) continues in Western Europe. The only countries where emissions increased were Turkey and Austria. In Turkey emissions increased because of lack of abatement measures and Austria due to fuel tourism.

EFFECTIVENESS OF POLICY REGULATIONS IN THE TRANSPORT SECTOR

This section investigates to what extent the decrease in Western European NO_x transport emissions can be associated to the introduction of the Euro standards. We analyse here how emission factors calculated on the basis of officially reported road transport emissions and activity data (implied emission factors) comply with the Euro standards outlined in Table 1.

Petrol consumption decreased (20%), while diesel consumption increased (90%) between 1990 and 2005. The shift to diesel is the impact of the European Automobile Manufacturers Association's commitment on the reduction of CO_2 emissions from passenger cars (Commission Recommendation 1999/125/EC). This agreement promoted the use of diesel passenger cars because they have up to 30% higher fuel efficiency than gasoline cars of similar size. The promotion of diesel cars greatly benefited the curtailment of greenhouse gases. At the same time, it should not be forgotten that diesel passenger cars emit as much as three times higher NO_x emissions per kilometre than gasoline cars of the same emission standard. Just to put it into perspective, assuming that the increase in fuel consumption would have originated from increase in petrol rather than diesel consumption (thus diesel consumption remaining at the 1990 levels), this would have led to some 1/3 lower NO_x emissions in 2005.

While the net fuel consumption in road transport increased (23%), road transport emissions decreased (44%) between 1990 and 2005. The emission reductions were largest for passenger cars (PC) (63%) followed by Heavy Duty Vehicles (HDV) (21%) and Light Duty Vehicles (LDV) (2%). There is a clear decoupling of emission and fuel consumption of PC already since 1990, as result of the developments in vehicle emission control technologies. For HDV the situation is more complex. Fuel consumption increased in all countries between 1990 and 2005, except in Germany, where HDV consumption decreased by 30% between 2000 and 2005. This substantial decrease in diesel sold is not likely due to technological developments alone, but also due to the high tax on diesel in Germany. The high fuel prices in Germany prevent transit traffic refuelling, and promote fuel tourism to other neighbouring countries. Emissions from HDV between 1990 and 2005 decreased in all countries, except in Spain, Portugal and Austria, where emissions increased, by more than 200% in the case of Austria. Austria is a counter case to Germany, in that some 30% of the diesel sold is consumed outside the country. With regard to LDV, their fuel consumption increased in all countries, while the emission levels have remained relatively stable. The above results show that the implementation of Euro standards has contributed to a decoupling of emissions and fuel consumption of all vehicle classes in Western Europe since 1990.

We have derived implied emission factors (IEF) in five-yearly intervals between 1990 and 2005 based directly on reviewed officially reported emissions and total (gasoline plus diesel) fuel consumption (Figure 1). In this way we can compare the average emission level of the whole fleet in each country, with the emission levels expected when developing the Euro standards. The results for Western Europe show that the IEFs decrease for all vehicle classes from 1990 to 2005. The average IEF reductions for all countries examined in this period are 67%, 42% and 35% for PC, LDV, and HDV respectively. The periods with largest IEF reductions vary with vehicle class and country. For PC, the largest IEF reductions (35%) occurred between 1995 and 2000 while max reductions for HDV (20%) appeared five years later. On average, the IEF reductions from LDV remained relatively constant at 17%. We know today that the introduction of electronic controls in Euro II (1997), and less so in Euro III (2001) HDV led to excessive NO_x emissions over operation modes that were not included in the type-approval test[17]. As a result, countries with a fast turnover of their HDV-fleet were delayed in meeting the stringent emission standards expected. This is the reason why the mean HDV-fleet emission factors in countries like the UK, Netherlands, Austria, Denmark, Switzerland in 2000 still appears higher than the Euro I emission standard introduced eight years before (1992). The situation improves in 2005 with only Austria and Denmark appearing to have HDV emission levels clearly beyond the emission standards eight years ago (Euro II).

The conclusions related to the effectiveness of the Euro emission standards for PC are less straightforward, since the IEF is a composite value of gasoline and diesel vehicle emission levels, while separate emission standards have been in place, depending on the fuel used. In general, the average fleet emission level in 2000 in several European countries corresponded to a level between the gasoline and diesel Euro 1 levels, eight years ago. Spain, with a rather old vehicle fleet including a fair share of gasoline cars, exhibits average 2005 emissions which are only marginally below the diesel 1992 levels. On the other hand, average PC fleet emissions in Germany and Switzerland seem quickly (e.g. within five years) to attain the emission standards, despite the large fleet of diesel passenger cars. A decadal delay in effective implementation of the Euro standards is also seen for LDV.

IEFs in Eastern European countries are more than twice as high as in Western European countries for PC. The result implies that the implementation of technological measures to abate road transport emissions has been less effective in Eastern Europe, because the Euro standards did not fully apply to Eastern European countries before their accession to the European Union in 2004, and due to a slower turnover of vehicles towards more modern, less polluting technologies.

CONCLUSIONS

Technological and policy developments to abate European emissions have clearly facilitated a substantial reduction in the NO_x levels. Between 1990 and 2005 road transport emissions decreased by more than 30 percent, but have now started to increase in many Eastern European recovering economies. Based on the development in road transport emissions, we determined three NO_x emission trend regimes in Europe. The regimes are demonstrated to be closely linked to policy developments.

The UN Protocol obligations may have led to substantial reductions, but we found that it was a lot easier to trace the effectiveness of the sector specific regulations. There is clear evidence that the Euro standards have been effective in bringing NO_x levels down. On the other hand, our study shows broadly in line with Zachariadis et al.[18] that it takes roughly ten years or more after the introduction of an emission standard to reach an equal level of average fleet emissions. This delay shows one of the inherent limitations with regard to the effectiveness of road transport policy. Although each new emission standard may introduce significant NO_x reductions over the one it replaces, it takes several years before a substantial portion of the fleet complies with the new emission standard. In order to fully account for the delay in compliance, it is important to note that introduction of new technologies was in some cases accompanied by HDV and PC emitting much higher in real-world operation than the emission standard level[17, 19], due to loopholes in the type-approval procedures. In addition, the substantial increase in diesel consumption in vehicles has hampered a more rapid NO_x abatement. The above considerations lead us to conclude that the policy aimed at reducing NO_x from the transport sector has not been as effective as the ambition level.

Some issues for future consideration are addressed. Due to the increase in diesel consumption, primary NO_2 emissions may be increasing in Europe, despite the overall reduction in NO_x. In diesel exhausts, excess oxygen may lead to much higher NO_2/NO_x ratios (50%) in vehicles equipped with oxidation aftertreatment (diesel oxidation catalyst or catalyzed filter) for PM control (AQEG, 2006) than for gasoline three-way catalytic converter cars (less than 5%). Current evidence shows that ambient concentrations of NO_2 do not decrease at the same rate as NO_x in various

European hotspots[2, 20], mainly due to the increasing NO_2 ratio in late diesel technology vehicles. Hourly NO_2 concentration limit values become mandatory in Europe starting from 2010 (EC Daughter Directive 99/30/EC). The proportion of primary NO_2 in vehicle exhausts may need to be addressed in future NO_x inventories. Another effect of the increase in diesel consumption in road transport is that less non-methane volatile organic pollutants (NMVOC) are emitted from this sector. The average NO_x/NMVOC emission ratio for PC and LDV has increased by a factor 2 between 1990 and 2005 according data officially reported to EMEP. The impact on tropospheric ozone production of the above EU wide changes in emission ratios from road transport should be further assessed by air quality modelling.

This paper does not analyse the implications for NO_x emissions from the transport sector by introducing larger proportion of biofuels in accordance with the EC biofuel directive (Directive 2003/30/EC), nor the contribution from international shipping on European NO_x emission levels, but these are nevertheless important subjects for future studies.

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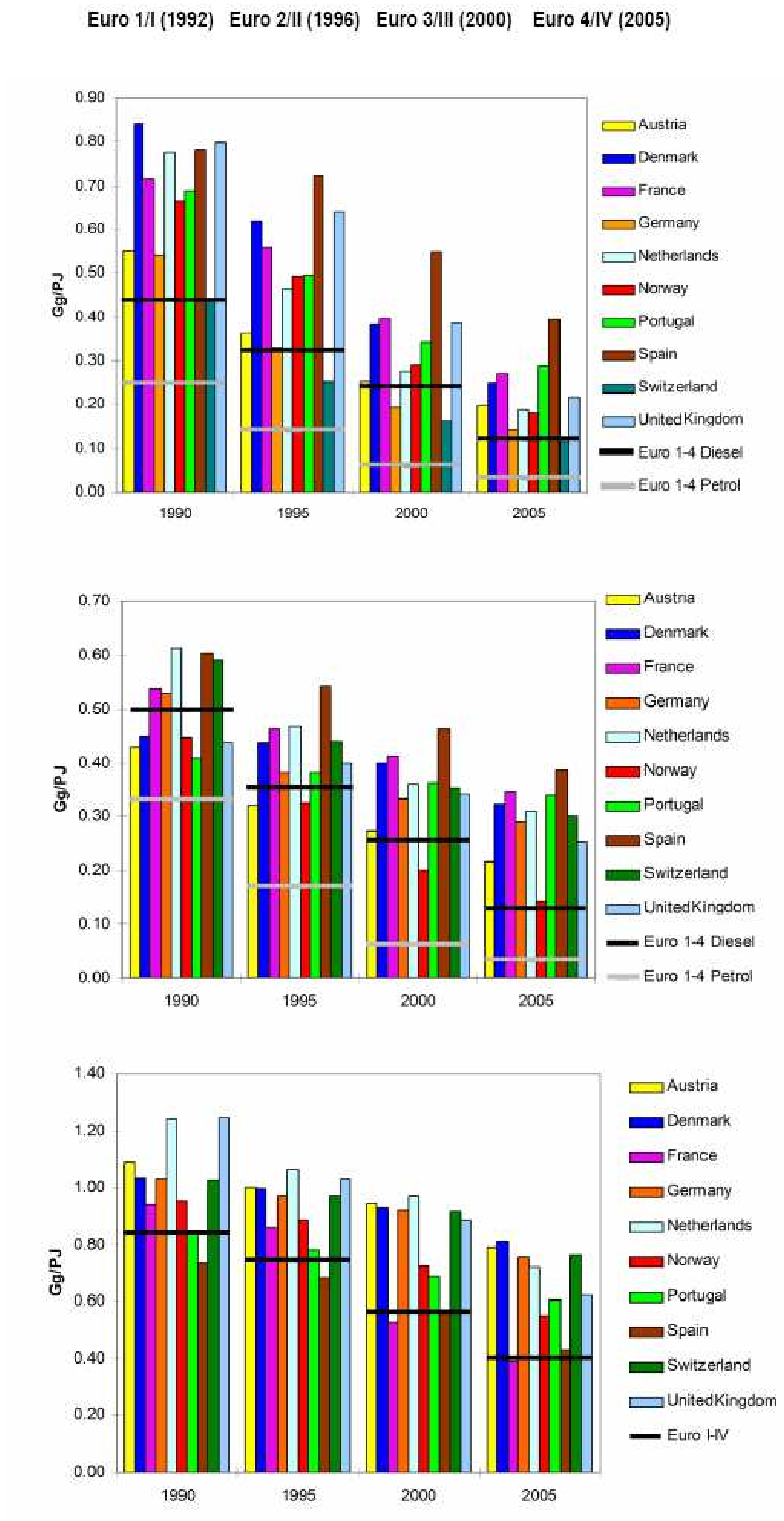
Table 1. Emission standards for road transport in Europe post-1992

Emission Standard	Regulation	Impl. Year [(1)]	NO_x (g/km) or (g/kWh)	NO_x (Gg/PJ) [Converted]	Main technology improvements over preceding step
Gasoline PCs and LDVs (g/km)					
Euro 1	91/441/EC	1992	0.62 [(2)]	0.25	Closed-loop TWC [(3)]
Euro 2	94/12/EC	1996	0.35 [(2)]	0.14	Faster light-off
Euro 3	98/69/EC	2000	0.15	0.06	Faster light-off and twin lambda control
Euro 4	98/69/EC	2005	0.08	0.03	Faster light-off and improved lambda control
Euro 5 & 6	EC 715/2007	2010-2015	0.06	0.02	Improved aftertreatment materials, deNOx for direct injection vehicles
Diesel PCs and LDVs (g/km)					
Euro 1	91/441/EC	1992	0.90 [(2)]	0.44	Improved combustion
Euro 2	94/12/EC	1996	0.67 [(2)]	0.32	Oxidation catalyst
Euro 3	98/69/EC	2000	0.50	0.24	Two oxidation catalysts, high pressure injection
Euro 4	98/69/EC	2005	0.25	0.12	Precise injection and pressure control
Euro 5	EC 715/2007	2010	0.18	0.09	Diesel particle filters
Euro 6	EC 715/2007	2010	0.08	0.04	deNOx, presumably SCR [(3)]
HDVs (g/kWh)					
Euro I	91/542/EEC	1992	8.0	0.84	Improved combustion
Euro II	91/542/EEC	1996	7.0	0.74	Electronic engine control
Euro III	1999/96/EC	2000	5.0	0.56	High pressure injection
Euro IV	1999/96/EC	2005	3.5	0.40	EGR, precise injection control
Euro V	1999/96/EC	2008	2.0	0.25	Cooled EGR [(3)] or SCR
Euro VI	Only draft proposal	2014	0.4	0.05	Presumably SCR+DPF [(3)]

(1) For LDVs and HDVs. For LDVs, the implementation date is roughly one year later than PCs to allow for calibration of new technology.
(2) Regulations set a standard for the sum of HC and NO_x emissions. The value quoted in the table is an inferred value based on typical HC/NO_x split for the particular vehicle technology.
(3) TWC: Three-way catalytic converter; SCR: Selective catalytic reduction;
DPF: Diesel particle filter

Figure 1. Implied emission factors 1990-2005 for Passenger Cars (top), Light Duty Vehicles (middle) and Heavy Duty Vehicles (bottom) compared to the Euro standards



KEY WORDS

Europe, NOx, emissions, traffic, trends, policy, measures