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Impact of selected policy measures on Europe's air quality

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Executive summary

In recent decades Europe has introduced and implemented a number of legislative instruments to improve air quality by controlling emissions of air pollutants that harm human health and the environment. In addition to legislation limiting emissions at the national level ([1]), these initiatives have also included specific legislation addressing emissions from road transport and industrial sectors. Nevertheless, present air quality levels in Europe still cause a variety of adverse impacts.

Industrial combustion (comprising emissions from power plants, refineries and from the manufacturing sector) remains an important source of air pollution, being a main contributor to emissions of particulate matter and acidifying pollutants. Road transport is a significant contributor to emissions of tropospheric ozone precursors. Together, these sources are responsible for around half to two-thirds of total emissions of these pollutants.

The main objective of the present study is to analyse and quantify the effects that certain past policy measures in the road transport and industrial combustion facilities have had on the magnitude of air pollutant emissions and subsequent air quality in Europe. The policies selected are the Euro emission standards for road vehicles and the EU directives on Integrated Pollution Prevention and Control (IPPC) and large combustion plants (LCP).

Two specific questions are addressed:

- how has the introduction of the selected legislative instruments affected air pollution in Europe during the past decades?
- what is the theoretical unexploited potential in Europe to reduce air pollution if all vehicles in Europe were to conform to the latest Euro standards and all industrial combustion facilities limited emissions to levels consistent with the LCP Best Available Techniques Reference Document?

Achievements of EU air emission policies

Road transport

Despite greater fuel use between 1990 and 2005 (+ 26 %), significant reductions in emissions have been achieved due to the introduction of the Euro standards in the road transport sector (starting in the early 1990s). This is especially so for carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC), whose emissions decreased significantly and steadily over the whole study period. By 2005, emissions of CO stood 80 % below those projected in a no-policy scenario — the theoretical situation that would have existed had Euro standards not been introduced. NMVOC emissions were 68 % lower.

Emissions of nitrogen oxides (NO_X) were 40 % below the no-policy scenario in 2005. Fine particulate matter ($PM_{2.5}$) were 60 % lower, with the decrease commencing in the mid-1990s.

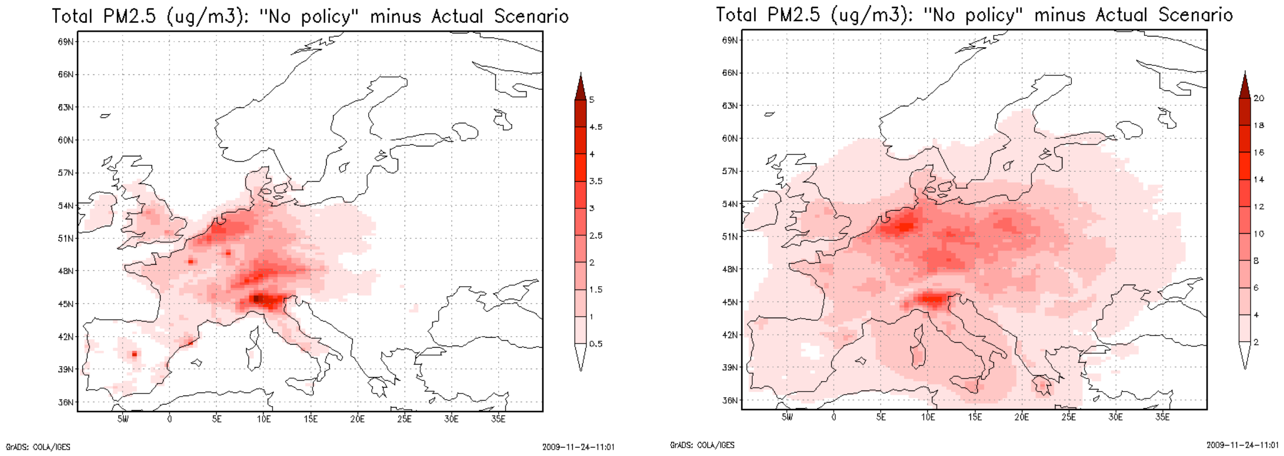
Due to lower emissions, concentrations of particulate matter over Europe have also fallen far below the levels that would have been observed had no policies been in place, mainly in densely populated areas in western European countries. Significant reductions in eastern Europe are not observed to the same extent.

Changes in tropospheric ozone concentrations are more complicated to ascertain. A decrease in high daily ([2]) ozone concentrations has occurred over most parts of Europe, especially in the Mediterranean area. Contrastingly, over Germany, the Netherlands and the United Kingdom an increase in tropospheric ozone has occurred as a result of lower chemical quenching rates of ozone due to lower NO_X emissions. Nevertheless, the introduction of the Euro standards has improved the overall health impacts of ozone for all countries. The effect on ecosystems (both crops and forests) is also positive.

([1]) For example, the European Union (EU) National Emission Ceilings Directive and the Gothenburg Protocol to the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP Convention).

([2]) This modelling result is based on the SOMO35 concept, an accumulated ozone concentration in excess of 70 µg/m^3, or 35 ppb, on each day in a calender year.

Figure ES.1 Improvement in fine particulate matter ($PM_{2.5}$) concentrations in Europe in 2005 following introduction of road vehicle emissions standards (left) and BAT in large industrial combustion plants (right)



Industrial combustion
The industrial combustion sector (including energy industries and manufacturing industries) has shown little overall change in its use of fuel between 1990 and 2005. The share of coal and oil in this sector is decreasing with time, while the share of natural gas and biomass are increasing. The use of energy for electricity generation has increased, while the energy use in the manufacturing industry has decreased over the period.

Emission projections were estimated using Eurostat fuel use data combined with emission factors for a 'no-policy' and 'full policy application' scenarios. For NO_X emissions, the actual emissions reported by countries mainly show reductions in the first half of the study period, while remaining more or less constant thereafter. Sulphur oxides (SO_X) emissions have been reduced more significantly, remaining differences in emissions between different countries are largely due to the differing sulphur content of fuels used. For both NO_X and SO_X, present emissions are significantly below the no-policy scenario in 2005.

The reduction in PM emissions from industrial combustion is more significant than that estimated in the road transport sector, and is highest in major industrialised areas such as Germany, Italy's Po Valley, the Netherlands and Poland. With regard to acidification, the policies have reduced sulphur dioxide (SO_2) concentrations in the same areas. The health benefits of this $PM_{2.5}$ reduction are, in terms of Years Of Life Lost (YOLL), about 60 %, compared to the no-policy scenario.

National ceilings
The emission reductions achieved by these sector-specific emission reduction measures should be placed in context against the intended emission reductions across all sectors in Europe between 1990 and 2010. The Gothenburg Protocol to the UNECE Convention on Long-range Transboundary Air Pollution and within the EU, the National Emission Ceilings Directive, both impose national ceilings (or limits) that must be met by 2010 for emissions of four key air pollutants (NO_X, SO_2, NMVOC and NH_3). Separate recent analysis (3) shows that many countries will not achieve their ceilings for one or more pollutants. Thus despite the documented past emission reductions achieved in the road transport and industrial combustion sectors (the focus of this report) Europe's air quality could have been further improved had all countries met their intended reduction commitments across all economic sectors.

Potential of current policies to reduce emissions further

Road transport
A considerable further reduction of emissions is possible under a '*full application*' scenario that theoretically assumes the latest Euro standards are implemented comprehensively in all European countries. The most important effects would be on NO_X from gasoline-fuelled vehicles and $PM_{2.5}$ from diesel-fuelled vehicles.

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(3) NEC Directive Status report 2009, EEA Technical report No 10/2010. European Environment Agency. http://www.eea.europa.eu/publications/nec-directive-status-report-2009 (accessed 20 September 2010).

A full application of the Euro standards would realise a further improvement in air quality concentrations of $PM_{2.5}$ by up to 3 µg/m^3. For tropospheric ozone, concentrations would decrease in the Mediterranean area, while in most densely populated areas (such as Germany, the Netherlands and the Po Valley) concentrations would increase (again due to the complex atmospheric chemistry of ozone and the NO_X quenching effect).

Reduced $PM_{2.5}$ exposure from road transport would have smaller potential health benefits than those for industrial combustion but would be positive for all EEA member countries (1–10 % in terms of YOLL). For SOMO35, health benefits attributable to ozone exposure are positive for most countries (up to 10 % in terms of the air quality impact indicator, years of life lost – YOLL) but negative for Belgium, Germany (both – 1 %) and the Netherlands (– 5 %).

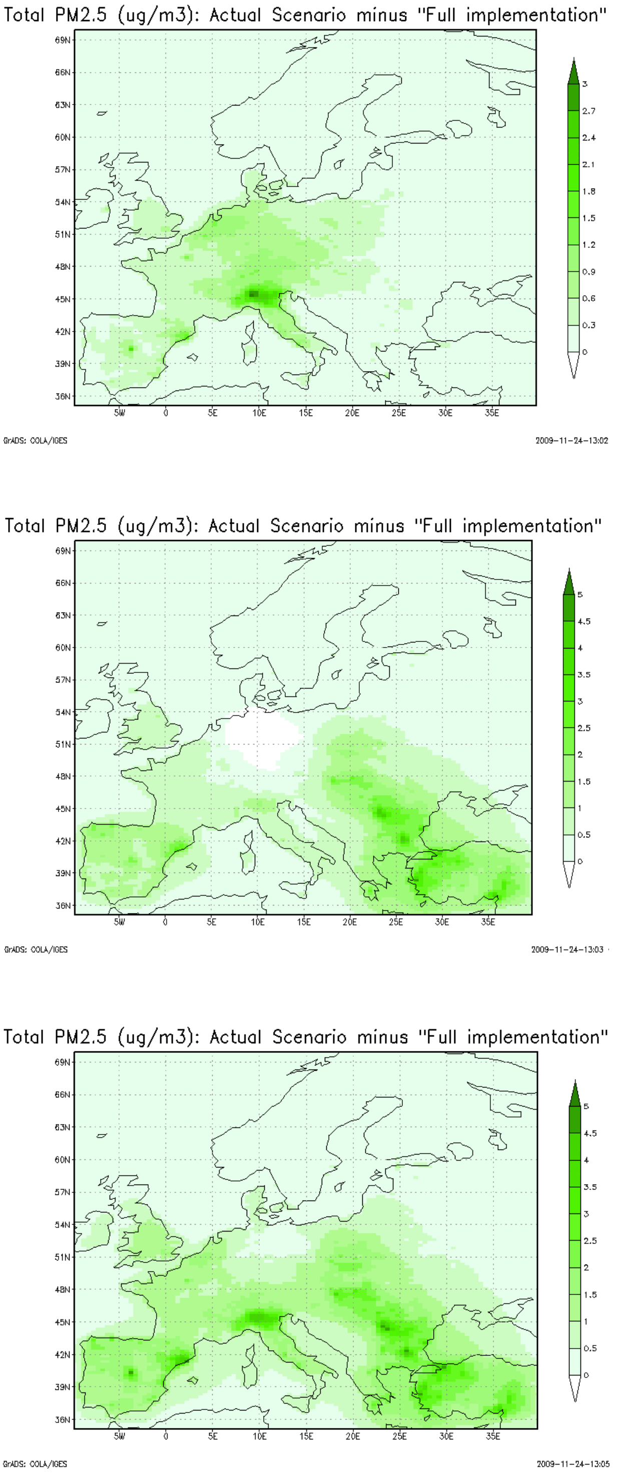
Industrial combustion

A '*full application*' scenario was similarly developed to identify the theoretical potential to reduce emissions of SO_2 and NO_X further, if emissions from industrial combustion facilities were consistent with the associated emission levels (AELs) described in the Large Combustion Plant Best Available Techniques (BAT) Reference Document (LCP BREF). It should be noted that the definition of industrial combustion facilities used in this study goes beyond that in the LCP BREF.

Current emission rates relative to fuel use in industrial facilities vary significantly among countries. Germany, for example, appears already to have both NO_X and SO_2 emissions at levels consistent with the AELs set out in the LCP BREF, while the same can be said for a number of EU-15 Member States for SO_2. In contrast, of the newer Member States, Bulgaria and Romania still appear to have largely unabated emissions for SO_2, while Latvia's NO_X emissions appear unabated. In many countries, emissions could be approximately halved if emissions were brought down to the AELs set out in the LCP BREF.

Total $PM_{2.5}$ concentrations would also decrease in most areas if countries reduced emissions to the LCP BREF AELs (Figure ES.1). However, in central Europe (Denmark, Germany and the Netherlands) no further decrease is expected because emissions are already largely consistent with the BREF AELs. High reduction potentials are mainly found in southern and eastern Europe.

Figure ES.2 **Theoretical potential improvement of fine particulate matter concentrations in Europe for 2005 had all vehicles complied with the latest Euro standards (top); all industrial combustion facilities had emissions consistent with BAT AELs as defined in the LCP BREF (middle); and the combination of the two scenarios (bottom)**



Combined policies
A combination of both the '*full application*' scenarios for the road transport and industrial combustion sectors results in the theoretical potential for:

- a further reduction of $PM_{2.5}$ concentrations over Europe, in all countries, ranging between 0 and 5 μg/m^3 (Figure ES.1);
- reduced tropospheric ozone concentrations in a large part of Europe, especially in the Mediterranean area, but some increases in highly industrialised and/or populated areas;
- beneficial drops in the ozone impact indicators SOMO35 and AOT40, except in England and Benelux countries, where values increase.
- net improvement in health impacts, as the health impacts arising from lower $PM_{2.5}$ exposure are much greater than those from the increase in tropospheric ozone exposure in certain areas,
- Europe's ecosystems as a whole to be less exposed to ozone, with 45 % of forests are exposed to ozone concentrations above critical levels (down from 60 % at present), and comparable reductions for crops.

Methodological notes

The evaluation of air quality in the study has been undertaken using the regional air quality model EURO-LOTOS, designed to address background air quality concentrations at a European scale. Therefore ozone and $PM_{2.5}$ (NO_2 and SO_2) mapped concentration fields and health impact assessments based on those fields are a result of or based on the (simplified) rural background modelling. It should thus be noted that human exposure to elevated air pollutant values can be much higher in urban and sub-urban areas than indicated by the model.

The model can also tend to underestimate $PM_{2.5}$ concentrations compared to measured data. These methodological issues are specifically discussed in the report with respect to regions such as the Italian Po Valley.

Conclusions

The past introduction of European air quality policies limiting emissions of the main air pollutants from road transport and large industrial combustion has significantly improved air quality and reduced air pollution-induced health effects that would otherwise have occurred. While this work focuses just on these two sectors, further improvements to Europe's air quality would occur had all countries achieved their intended emission reduction commitments between 1990 and 2010.

A comparison of current emissions with a theoretical situation in which the latest emission standards for the road transport sector and BAT associated AELs for large combustion plants are fully applied, indicates there is significant scope to reduce emissions further and hence improve air quality in most regions.

It can be noted, however, that the situation concerning secondary air pollution by tropospheric ozone precursors is more complicated. Due to complex non-linearities in the atmospheric chemistry of ozone and its precursors (see Box 2.2 of this report), lower emissions of specific ozone precursors may actually yield higher ozone concentrations in some areas. Targeted, effective actions to reduce ozone concentrations further at the regional and hemispheric scale are therefore needed.

Glossary

AEL	Associated Emission Level (associated with BAT as set out in the BREFs)
BAT	Best available techniques
BREF	BAT Reference Document
CO_2	Carbon dioxide
COPERT	COmputer Programme to calculate Emissions from Road Transport
DPSIR	Drivers, pressures, state, impacts, responses analysis framework
EEA-32 countries	EU-27 Member States, the four EFTA countries and Turkey
EFTA countries	Iceland, Liechtenstein, Norway, Switzerland
ELV	Emission Limit Value in the context of the LCP Directive
ETC/ACC	European Topic Centre for Air and Climate Change
EU-27 Member States	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies emissions model developed by IIASA
IIASA	International Institute for Applied System Analysis, Austria
IPPC	Integrated Pollution Prevention and Control (Directive)
LCP	Large Combustion Plant (Directive)
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides
PM	Particulate matter
PM_{10}	Particulate matter with a diameter equal to or below 10 μm
$PM_{2.5}$	Fine particulate matter with a diameter equal to or below 2.5 μm
SO_2	Sulphur dioxide
SO_X	Sulphur oxides
TEAM	TNO Emissions Assessment Model
TNO	Netherlands Organisation for Applied Scientific Research
UNECE	United Nations Economic Commission for Europe

1 Introduction

Within the European Union (EU), the Sixth Environment Action Programme (6th EAP) running from 2002 to 2012 (EC, 2002), aims to achieve levels of air quality that do not result in unacceptable impacts on, and risks to, human health and the environment. Over recent decades, the European Union has introduced and implemented various legal instruments to improve air quality by controlling emissions of air pollutants harmful to health and the environment. Such initiatives have included for example, sectoral legislation in both the road transport and industrial areas.

Despite these efforts, current air quality in Europe still leads to a number of adverse impacts, including:

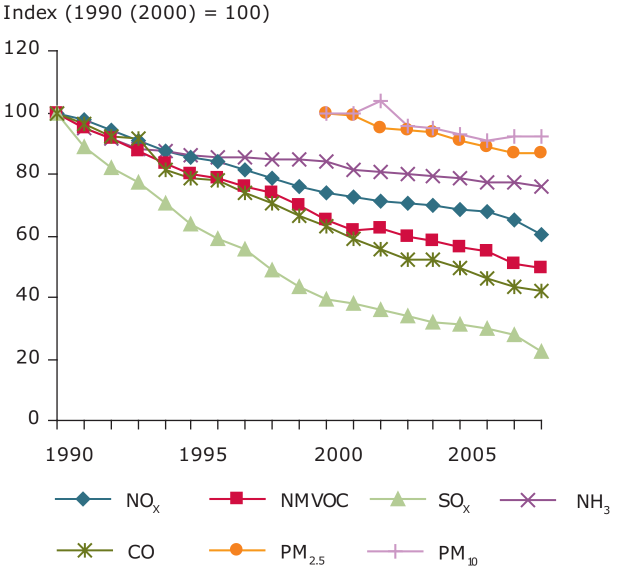
- effects on human health caused by exposure to particulate matter and ozone (and to a lesser extent NO_2, SO_2, CO, lead and benzene);
- eutrophication and to a lesser extent acidification of ecosystems;
- damage to ecosystems and crops through exposure to ozone;
- damage to materials and cultural heritage (e.g. monuments) due to exposure to acidifying pollutants and ozone;
- impacts of heavy metals and persistent organic pollutants on human health and ecosystems.

In terms of air quality, it is possible to identify three main groups of pollutants that contribute to many of the respective impacts listed above, specifically:

- primary particulate matter and secondary particulate matter precursors, i.e. NO_X, SO_2, and ammonia (NH_3);
- ozone precursors, i.e. NMVOC, NO_X, methane (CH_4) and CO;
- acidifying pollutants, i.e. NO_X, SO_2, and NH_3.

The pollutants contribute to different extents to each of these issues. Figures 1.1 and 1.2 illustrate the emission trends made by selected pollutants since 1990, and the contribution that different sectors make to emissions of these pollutants.

Figure 1.1 Emission trends for selected air pollutants, EU-27

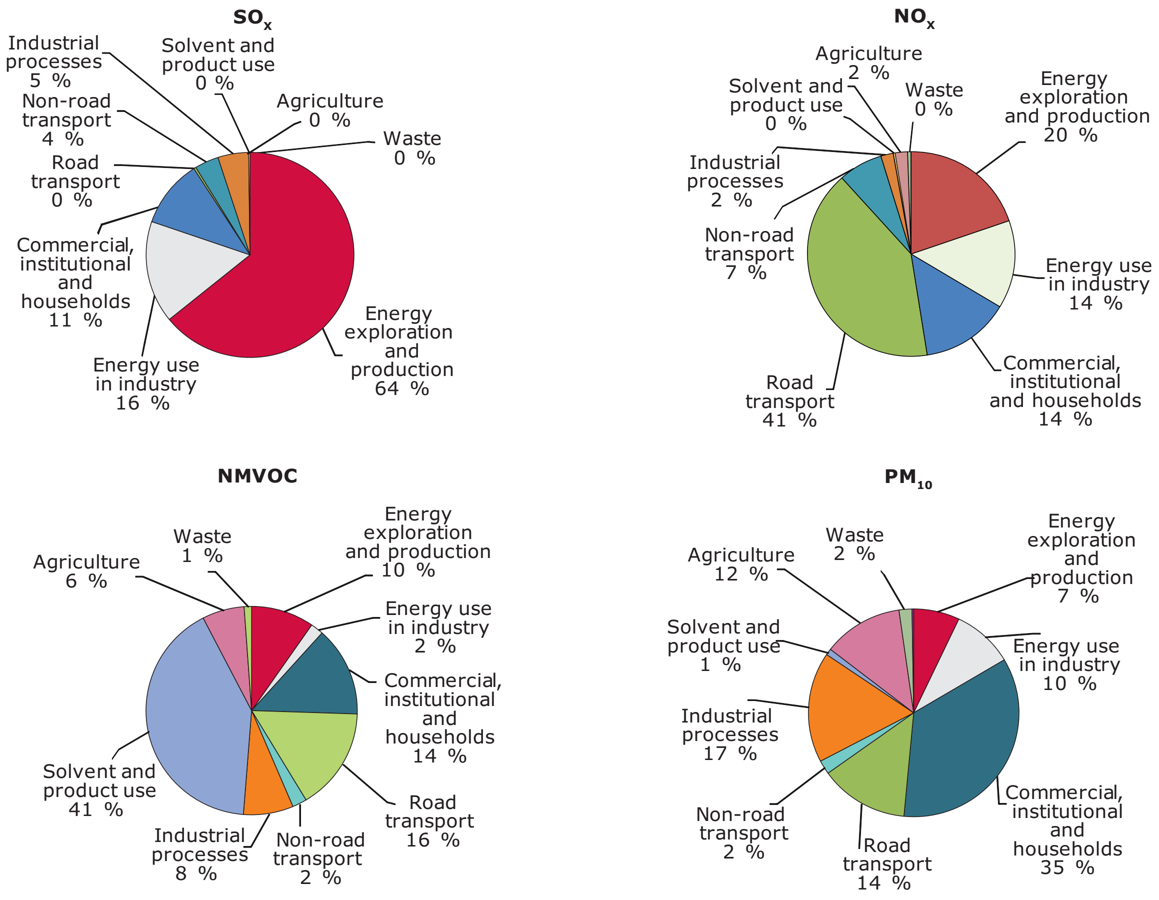


Source: EEA, 2010.

Figures 1.1 and 1.2 show clearly that for the selected pollutants, generally significant emission reductions have been achieved over time. Nevertheless, as noted above, air quality in Europe still causes adverse impacts. The charts also show that emissions arising from fuel combustion in energy sectors (e.g. energy generation and industrial sectors) are important contributors to emissions of particulate matter and acidifying pollutants, whereas road transport is a significant contributor to tropospheric ozone precursor emissions.

It is of course no coincidence that a number of past European emission abatement policies have been specifically directed towards reducing emissions from the road transport and large combustion plant sectors. A description of the general air pollutant policy framework within Europe is provided in Section 1.2 of the present chapter.

Figure 1.2 The contribution made by different sectors to total emissions in 2008, EU-27



Source: EEA, 2010.

1.1 Objectives

Following the introduction and implementation of legislation for the road transport and large combustion plant sectors, it can take a significant period of time before efforts to reduce or control emissions are fully realised, and hence benefits in terms of air quality are observed. There can be a number of reasons for this. For both the road transport and industrial combustion sectors, equipment has a relatively long technical and economic lifetime. This leads to significant time lags between the introduction of say, emission control measures (that cannot or are not retro-fitted), and reaching a 'complete' level of implementation'. One can therefore often expect that policies already in place will still lead to lower emissions and improved air quality in the future as the stock of older equipment is steadily replaced.

A main objective of this study is to analyse and quantify the effects that selected past policy measures in the road transport and large combustion plant sectors have had on both the magnitude of air pollutant emissions and the subsequent levels of air quality in Europe. This has been done by looking at two questions:

- how has the introduction of the selected EU legislative instruments affected air pollution in Europe over the past decades?
- what is the theoretical potential in Europe to reduce air pollution further in the future under existing legislation (i.e. if all vehicles in Europe were to conform to the latest Euro standards, and all combustion facilities were to limit emissions to the Associated Emission Levels cited in the LCP BREF)?

1.2 Relevant European air pollutant policy frameworks

1.2.1 *National emission ceilings*

Within the EU, the National Emission Ceilings (NEC) Directive (EC, 2001b) imposes ceilings (or limits) that must be met by 2010 for emissions of four key air pollutants (NO_X, SO_2, NMVOC and NH_3) that harm human health and the environment. Internationally, the issue of air pollution emissions is also addressed by the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (the LRTAP Convention) and its protocols (UNECE, 1979). The Gothenburg 'multi-pollutant' Protocol to the LRTAP Convention (UNECE, 1999) also contains 2010 national emission ceilings for those countries that have ratified the protocol. For the EU Member States, these ceilings are either equal to or less ambitious than those in the NEC Directive. Both the NEC Directive and Gothenburg Protocol are currently under review.

The overall goals of bringing emissions down below the agreed ceilings are supported by sector-specific emission reduction measures. Three important pieces of legislation in this respect are:

- Euro standards for road vehicles (e.g. EC, 2007);
- The EU Large Combustion Plant (LCP) Directive (EC, 2001a);
- The EU Integrated Pollution Prevention and Control (IPPC) Directive (EC, 1996).

Together, these measures tackle many of the most important contributing sources to the issues of acidification, tropospheric ozone and particulate matter formation.

1.2.2 *Road transport sector*

The European Union has been committed over the past 20 years to developing and implementing policies aimed at a cleaner European vehicle fleet in terms of air pollutant emissions. In the 1970s and 1980s the Economic Commission for Europe (ECE) developed a set of phased standards to reduce air pollutant emissions from the automotive sector. The ECE 15/00-01, ECE 15/02, ECE 15/03 and ECE 15/04 regulations were in force in 1969–1970, 1971–1975, 1976–1983 and 1984–1987, respectively and were solely targeted at gasoline-powered passenger cars and their related pollutants. Diesel vehicles, two-wheelers and heavy duty vehicles were not covered.

Directly following and building upon these regulations, the European Commission developed a series of requirements (the European Vehicle Emission Standards, a.k.a. Euro standards,(4) defining limits for exhaust emissions of new vehicles sold within the EU. Non-compliant vehicles cannot be sold in the EU. New standards do not apply to vehicles already on the road.

Retrofitting of certain emission abatement technologies can, however, occur at a later stage of the implementation of a standard, years after the applicable standard first came into force (i.e. phased application). For instance Euro 5 requires that particle filters be retro-fitted on existing diesel passenger cars and light duty vehicles sold before

Table 1.1 Introduction dates (*) of the Euro emission standards for road vehicles

Vehicle category	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Passenger cars	Jul 1992	Jan 1996	Jan 2000	Jan 2005	Sep 2008	Sep 2013
Light commercial vehicles (N1-I)	Oct 1993	Jan 1996 (gasoline, LPG) 1998 (diesel)	Jan 2000	Jan 2005	Sep 2009	Sep 2014 (diesel only)
Light commercial vehicles (N1-II & III)	Oct 1993	Jan 1996 (gasoline, LPG) 1998 (diesel)	Jan 2001	Jan 2006	Sep 2009	Sep 2015 (diesel only)
Trucks and buses	1992	1995	1999	2005	2007	
Motorcycles	2000	2004	2007			
Mopeds	2000	2004	2007			

Note: (*) All vehicles need to meet the standards a year after the given date. The dates from which Euro standards apply simply provide a guide to what the emissions standards a vehicle will have, depending upon when it was manufactured. Exceptions exist for some vehicles, since some vehicle models met standards earlier than they were legally required to, and a few low production models are given extensions for compliance.

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(4) Euro standards for passenger cars and light duty vehicles (vans) are commonly denoted with Arabic numerals (i.e. Euro 1, 2, 3, 4, 5, 6, …) while those for heavy duty vehicles and two-wheelers are denoted with Roman numerals (i.e. Euro I, II, III, IV, V, VI, …).

the standard came into force. The Euro standards have been, and continue to be, introduced in phases, with the introduction times and actual standards varying by pollutant, vehicle category and vehicle weight class or engine volume and fuel type (see Table 1.1 for a summary of the introduction dates for each of the Euro standards).

In addition to the Euro standards, the European Union also has implemented the Sulphur and Lead in Fuels Directive of 2003 (EC, 2003). This directive requires Member States to ensure that unleaded petrol and diesel fuel with a maximum sulphur content of 10 mg/kg are marketed within their territories by no later than 1 January 2005. By no later than 1 January 2009 they must have ensured that unleaded petrol and diesel fuel marketed in their territory complies with the environmental specifications set out in Annexes III and IV of the directive. The present study does not attempt to assess the impact of the Sulphur and Lead in Fuels Directive.

1.2.3 *Large combustion plants*

LCP Directive

In 2001, the EU adopted the revised Large Combustion Plant Directive, which specifies emission limits for combustion plants having a rated thermal input equal to or greater than 50 megawatts. The directive mainly covers plants generating electricity and/or heat and exempts particular types of combustion plants (see its article 2(7)). The LCP Directive sets Emission Limit Values (ELVs) (5) for sulphur dioxide (SO_2), nitrogen oxides (NO_X) and dust (PM), which vary according to the age of the plant, the fuel used and the plant capacity (Table 1.2). In the context of this study, the LCP Directive is only relevant as a driver of emissions in the past, and not in the context of assessing the potential for future reductions.

IPPC Directive

The European Union adopted the Integrated Pollution Prevention and Control Directive in 1996 (EC, 1996). Formal compliance for new installations was required by 30 October 1999 and compliance for existing installations by 30 October 2007. In the directive, the concept of 'best available techniques' or BAT (JRC, 2010) plays a central role. In this context:

- 'techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- 'available' techniques are those developed on a scale that allows application in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, and as long as they are reasonably accessible to the operator;

Table 1.2 Examples of Emission Limit Values for NO_X, SO_2 and dust as specified in the LCP Directive for existing plants and new plants having started operating before 27 November 2003

Pollutant	Capacity (MW_{th})	ELV (mg/Nm^3)		
		Solid fuels (except biomass)	Liquid fuels	Gas (*)
NO_X	> 500	500 (200 after 1 January 2016)	400	200
	50–500	600	450	300
SO_2	> 500	400	400	35 (*)
	100–500	2 000–400 (linear decrease)	1 700 (100–300 MW_{th}) 1 700–400 (300–500 MW_{th}; linear decrease)	
	50–100	2000	1700	
Dust (PM)	> 500	50	50	5 (*)
	50–500	100	50	

Note: (*) Gaseous fuels in general; exceptions exist in the directive.

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(5) Under the LCP Directive, Member States have certain opt-out provisions (Article 4(4)) and may define and implement national emission reduction plans (NERPs) (Article 4(6)).

- 'best' means most effective in achieving a high general level of protection of the environment as a whole.

Operators of relevant industrial installations must apply BAT to prevent and control pollution. Authorities are also obliged to set up a system of issuing integrated permits that will lead to the implementation of BAT in new and existing plants.

Conclusions as to what are considered to be BAT at the EU level for the activities covered by the directive are given in BAT Reference documents (or so-called BREFs), which are developed under the coordination of the Commission (EU IPPC Bureau, DG JRC), through an exchange of information by expert groups comprised of representatives of the EU Member States, industry, NGOs and other stakeholders.

As earlier noted, the definition of industrial combustion facilities used in this study goes beyond that in the LCP BREF. The LCP BREF covers, in general, combustion installations with a rated thermal input exceeding 50 MW. This includes the power generation industry and those industries where 'conventional' (commercially available and specified) fuels are used and where the combustion units are not covered within another sector BREF. In this study, industrial combustion facilities comprise power plants, refineries and those in the manufacturing sector regardless of capacity.

The LCP BREF, which was adopted in 2006 (JRC, 2010), defines BAT and BAT-Associated Emission Levels (AELs), indicating the expected pollutant concentrations in the stack when BAT are used. AELs are typically expressed as a range of values. Table 1.3 presents an overview of the upper (i.e. least stringent) and lower (i.e. most stringent) end values of the BAT AEL ranges for NO_X, SO_2 and dust for existing boilers.

Industrial emissions directive

In December 2007, the European Commission adopted a proposal for an Industrial Emissions Directive (EC, 2010), recasting a number of directives regarding industrial emissions (including the present IPPC and LCP Directives) into one legislative instrument. The Commission proposed that minimum emission limit values in certain industrial sectors should be tightened — particularly for large combustion plants where progress to reduce pollution is considered insufficient. It has proposed that the scope of the directive should be

Table 1.3 BAT Associated Emission Levels (BAT AELs) for NO_x, SO_2 and dust for existing LCPs (boilers) as set out in the LCP BREF

Pollutant	Type	Capacity (MWth)	Emission level (mg/Nm^3)				
			Hard coal	Brown coal	Fuel oil	Other oil	Gas(*)
NO_x	BREF, 'upper end' of BAT AEL	> 300	200	200	150	150	100
		100–300	200	200	200	200	100
		50–100	300	450	450	450	100
	BREF, 'lower end' of BAT AEL	> 300		50	50	50	20
		100–300		90	50	50	20
		50–100	90	200	150	150	20
SO_2	BREF, 'upper end' of BAT AEL	> 300	200	200	200	200	10
		100–300	250	250	250	250	10
		50–100	400	350	350	350	10
	BREF, 'lower end' of BAT AEL	>300	20	50	50	50	10
		100–300	100	100	100	100	10
		50–100	150	100	100	100	10
Dust (PM)	BREF, 'upper end' of BAT AEL	>300	20	20	20	20	
		100–300	25	25	25	25	
		50–100	30	30	30	30	
	BREF, 'lower end' of BAT AEL	> 300	5	5	5	5	
		100–300	5	5	5	5	
		50–100	5	5	5	5	

Note: (*) The NO_x emission levels of dust caused by using natural gas as a fuel are normally well below 5mg/Nm^3 and SO_2 emissions are well below 10 mg/Nm^3 (15 % O_2) without any additional technical measures being applied. Dust emissions are well below 5 mg/Nm^3 without any additional abatement techniques applied (LCP BREF, see JRC, 2010).

Source: EEA, 2008b.

extended compared to the existing legislation to include also medium-sized combustion plants, i.e. those between 20 and 50 MW thermal input. The proposal is presently in its second reading before the European Parliament and Council.

1.2.4 EU Air Quality Directive

The EU Air Quality Directive (EC, 2008) entered into force on 11 June 2008 and replaced the earlier Air Quality Framework Directive (96/62/EC) and a number of its 'daughter' directives. The new Air Quality Directive establishes ambitious, cost-effective target and limit values for improving human health and environmental quality up to 2020. In the directive, standards to protect human health are not valid in, for example, areas where the general public is not allowed access and in uninhabited areas. Table 1.4 summarises the standards relevant for the pollutants and indicators considered in this study.

Table 1.4 Summary of EU air quality limit and target values for NO_2, PM_{10}, $PM_{2.5}$ and ozone (Air Quality Directive, 2008/50/EC)

Pollutant	Protecting	Period of analysis	Value	Status
Nitrogen dioxide (NO_2) (a)	Humans	Annual mean	40 µg/m^{-3}	Limit value; valid from 2010
	Humans	Hourly mean; exceedances may occur for a maximum of 18 hours per year	200 µg/m^{-3}	Limit value; valid from 2010
Particulate matter (PM_{10}) (b)	Humans	Annual mean	40 µg/m^{-3}	Limit value
	Humans	Daily mean; exceedances may occur for a maximum of 35 days per year	50 µg/m^{-3}	Limit value
Particulate matter ($PM_{2.5}$)	Humans	Annual mean	25 µg/m^{-3}	Target value, to be reached in 2010; limit value enters into force in 2015
	Humans	Annual mean, averaged over observations in urban background locations (c)	20 µg/m^{-3}	Limit value; Valid from 2015
	Humans	Annual mean, averaged over observations in urban background locations (c)	15–20 % reduction	Exposure reduction target value; to be reached in 2020 relative to 2010
Ozone (O_3)	Humans(d)	Maximum daily 8 hour mean; exceedances may occur for a maximum of 25 days per calendar year	120 µg/m^{-3}	Target value; to be reached in 2010
	Vegetation	AOT40,(e) accumulated over May, June and July	18 000 (µg/m^{-3}).h	Target value to be reached in 2010
Sulphur dioxide (SO_2)	Humans	Hourly mean	350 µg/m^{-3}	Limit value; valid since 2005
	Humans	Daily mean	125 µg/m^{-3}	Limit value; valid since 2005

Notes: (a) Postponement of compliance with standards is possible under specific conditions until 2015.

(b) Postponement of compliance with standards is possible under specific conditions until 2011. When testing for compliance, the natural dust contribution (including sea salt) may be subtracted from the observed values where exceedances occur.

(c) Instead of focussing on short-term local acute exposure, the directive focuses on reducing large scale chronic exposure to $PM_{2.5}$ and has set a standard and targets with respect to the 'average exposure indicator' (AEI). The AEI standard of 20 µg/m^{-3} is valid from 2015. Exposure reduction targets have been set for 2020.The exposure reduction target depends on the AEI observed for the year 2010 and varies between 0 % (when the AEI in 2010 is below 8.5 µg/m^{-3}) to more than 20 % when the AEI in 2010 exceeds 22 µg/m^{-3}. The AEI is based on three-year average urban background concentrations. The AEI for 2010 is determined over the period 2008–2010 or over 2009–2011. The AEI for 2020 is determined for the period 2018–2020.

(d) The World Health Organisation additionally recommends SOMO35 as the most appropriate indicator for estimating the cumulative exposure of the human population to ozone. SOMO35 is the Sum Of excess daily Maximum 8-hour Ozone means above a cut-off point of 35 ppb calculated for all the days in a year.

(e) The AOT40 (expressed in (µg/m^{-3}).h) means the sum of the difference between hourly concentrations greater than 80 µg/m^{-3} (40 ppb) and 80 µg/m^{-3} over a given period using only the hourly values measured between 08:00 and 20:00 CET. For crops the AOT40 is accumulated over the three month period May–July while for forest the six month period April–September is considered.

1.3 Earlier studies

Various previous studies have assessed the effectiveness of measures to reduce emissions of harmful pollutants from the road transport and industrial combustion sectors, analysing the effectiveness of existing and proposed policy scenarios in different ways.

When EU legislation is in draft form (i.e. before its adoption by the European Parliament and Council) the European Commission must carry out formal (environmental) impact assessments. These aim to establish the impact areas and cost-effectiveness of the proposed legislation through analysis of the scenario with and without the proposed measure. The findings may then be used to refine the proposed legislation.

A number of country-specific studies have also analysed vehicle emissions using scenarios for control strategies and long-term environmental targets (Johansson, 1998; Lumbreras *et al*., 2008; Vestreng *et al*., 2008). In particular, Vestreng et al. (2008) analyse the evolution of NO_X emissions in Europe (1880 to present) with a focus on road transport control measures. The authors identify five trend regimes:

1. 1880–1950, characterised by a slow increase in fuel consumption Europe-wide;
2. 1950–1980, characterised by a continued steep upward trend in liquid fuel use and the introduction of the first regulations on road traffic emissions;
3. 1980–1990, characterised by a reduction in fuel consumption and differences between eastern and western Europe;
4. 1990–2000, involving a turning point for road traffic emissions, with a general decrease of emissions in Europe;
5. 2000–2005, in which economic recovery contributes to increased emissions from road transport in eastern Europe, while emissions in western Europe continue to decrease.

Vestreng *et al*. (2008) concluded that even though the effectiveness of Euro standards 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 between 1990 and 2005. In contrast to the current study, Vestreng *et al*. limit the discussion to emissions; concentrations and associated environmental impacts were not considered.

The International Institute for Applied System Analysis (IIASA) have also conducted much work under the Clean Air for Europe (CAFE) programme and later in the context of the NEC Directive and Gothenburg Protocol revisions (Amman *et al*., 2005a, 2005b, 2005c, 2005d, 2008) using the RAINS/GAINS model. The CAFE programme was a comprehensive assessment of available measures to improve European air quality beyond the achievements expected from the full implementation of all existing air quality legislation. The studies provide country-specific details on emission reductions, emission control costs and associated environmental impacts of policy scenarios. The studies focused mainly on PM, SO_2, NO_X, acid deposition, eutrophication and tropospheric O_3. They considered both mobile and stationary pollution sources.

One of the key differences between the IIASA studies and the present study is that the former generally consider different combinations of existing air-quality-related legislation and/or parts thereof to look at future scenarios (i.e. the health and environmental impacts associated with emission projections). By contrast, the present study focuses on past emission trends, their impacts and three specifically selected legislative instruments. The level of detail of analysis is also somewhat different, in that the current study has made use of recent data on vehicle fleets, technologies, emission factors, energy consumption and legislation introduction dates for Europe, consistent as far as possible with official statistics and emission reports from countries. A one-to-one comparison of the methodologies and findings of the IIASA studies and the current one is, therefore, not always possible.

An earlier EEA report (EEA, 2008b) also quantified the theoretical SO_2 and NO_X emission reduction potential in electricity-generating large power plants through implementation of BAT defined under the IPPC Directive. In the current study, the potential gains of implementing BAT are also quantified, based on the previous EEA report. The main difference between the earlier EEA study and the current report is that the former considered effectiveness at the level of individual power plants, whereas the current study utilises a more generally applicable methodology, considering conditions averaged at the national level.

1.4 Structure of this report

Chapter 2 presents information on the data and assessment methods which were used in the study.

Chapter 3 presents the results of a retrospective analysis, looking back over the period 1990–2005 to ascertain what the emission reduction policies have achieved.

Chapter 4 presents a prospective analysis, evaluating what more can be achieved through a theoretical 'full' implementation of current policies.

Both Chapters 3 and 4 are structured according to the DPSIR logic, discussing the drivers (fuel use), pressures (emissions), state (concentrations) and impact (on health and ecosystems) in turn.

Finally, Chapter 5 presents the conclusions of the study and recommendations.

2 Methodology and data sources

2.1 General approach

The two specific policy questions addressed by this study (see Section 1.1 above on objectives) were analysed using three different scenarios. Rather than looking into the future, the scenarios assess the current situation by assuming certain past developments. The three retrospective scenarios thus comprise:

- an '***actual scenario***', which models the developments in emission and air quality trends in the period (1990–2005) based on the measures actually introduced, and can be tested against the officially reported data from countries;
- a '***no application scenario***', which estimates how emissions and air quality would have developed had abatement measures (i.e. vehicle ECE-15 and Euro standards, and the IPPC Directive) not been introduced;
- a '***full application scenario***', which assesses, theoretically, how the emissions and air quality could have developed had the relevant legislation (i.e. the Euro standards, and the IPPC directive) been fully applied for all sources considered which are covered by the respective legislation without any time lag (and without taking into account the exceptions, derogations and flexibilities that were provided for in the original legislation). In this regard, the '*full application*' scenario is in essence a '*maximum feasible reduction*' type scenario.

The study thus adopts a comparative-statistical analysis by comparing the actual 1990 and 2005 situation with both a 'without', and 'with' full policy scenario. The approach employed means that the study does not take into account the dynamism in economic actors (e.g. households, relevant companies) of adapting to new conditions – not just with respect to early or later implementation of the required changes, but also in terms of changing behaviour, technology, markets, inputs etc. as the consequence of the (foreseen) requirements. In turn this may or may not imply that the impact of implemented policies is actually even greater than the analysis demonstrates.

2.2 Emission calculations

In this study, emissions have been calculated using the TNO Emission Assessment Model (TEAM) (Pulles *et al*., 2006; Pulles *et al*., 2007; see also Annex 1 to the present report). The model allows for differentiation between activity and technology parameters.

Activity scenarios

- Three activity scenarios are considered: one based on the activity in the road transport and industrial combustion sectors as actually recorded, and two others in which activity growth is assumed to be identical to the observed growth in either the population or the economy (based on Eurostat population and gross domestic product data).

Technology scenarios

In the model, activities are performed with specific technologies. This study uses three different technology scenarios:

- the '***actual scenario***' reconstructing the actual time trend in introducing the respective technologies;
- the '***no application scenario***', assuming that the technologies would have been unabated for the full time series;
- the '***full application scenario***', assuming that as soon as a technology is available, it is used for all activity in a given country.

The activity scenarios are used to analyse the historic trend in the activity data. The technology scenarios assess the past and potential effects of introducing specific abatement measures.

2.2.1 *Road transport sector*

Fuel consumption in road transport
Data on total fuel consumption by the road transport sector in each country were obtained from Eurostat (2008). Using TREMOVE data (TREMOVE, 2010), fuel use was stratified over vehicle types: mopeds and motorcycles; light duty vehicles (passenger cars and vans); and heavy duty vehicles (trucks, buses and tractors). A further detail was introduced to represent vehicle weight, engine volume and technology type. This procedure is summarised and graphically illustrated in Figure 2.2.

Figure 2.1 presents the fuel consumption calculated for the aggregate of all vehicle categories and all fuel types according to the methodology in Figure 2.2. The left panel of Figure 2.1 shows that the consumption of diesel in the study area between 1990 and 2005 almost doubled. In contrast gasoline consumption decreased during this period, while the use of LPG increased. LPG accounted for a small share of the fuel used in the road transport sector. Total fuel consumption in the road transport sector between 1990 and 2005 increased by 26 %.

The right panel of Figure 2.1 shows that fuel consumption is increasing for passenger cars, heavy duty trucks and light duty vehicles. For motorcycles, the energy use has remained fairly constant throughout the study period. Only for buses and mopeds is fuel use decreasing. However, since their contribution to the total energy consumption is small, this effect is insignificant and the overall fuel consumption in road transport shows a steadily increasing trend

Using specific fuel use by vehicle type and vehicle class (see Annex 2 to the present report), energy use can easily be converted to vehicle kilometres.

Technologies and emission factors
Annex 2 provides an overview of all vehicle types and classes and the associated technologies with emission factors. These data are derived from combining TREMOVE and EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2009) data into more than 2100 emission factors. The specific technologies are grouped under 'policies' for clarity.

TREMOVE fleet data were used to estimate the penetration of emission abatement technologies into total activity by different vehicle types over time. Figure 2.3 displays the results at the European level. The figure shows that a large share of conventional gasoline and diesel-powered vehicles has since been replaced by vehicles compliant with the Euro vehicle emission legislation. A smaller proportion of LPG-fuelled vehicles (not shown) has similarly been updated.

Each of the technologies considered in this study has a set of associated emission factors for each relevant pollutant. The emission factors were sourced from the EMEP/EEA Air Pollutant Emissions Inventory

Figure 2.1 Activity rates for the road transport sector in EEA-32 countries; left by fuel type, right by vehicle type

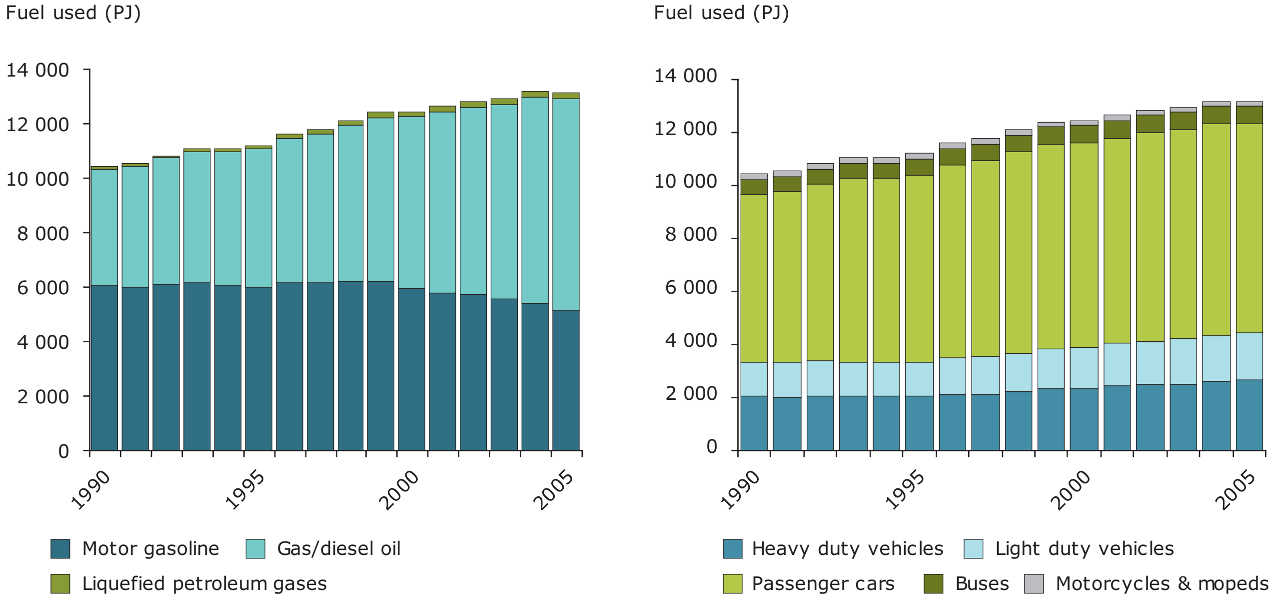


Figure 2.2 Methodology used to calculate road transport emissions using the TEAM model

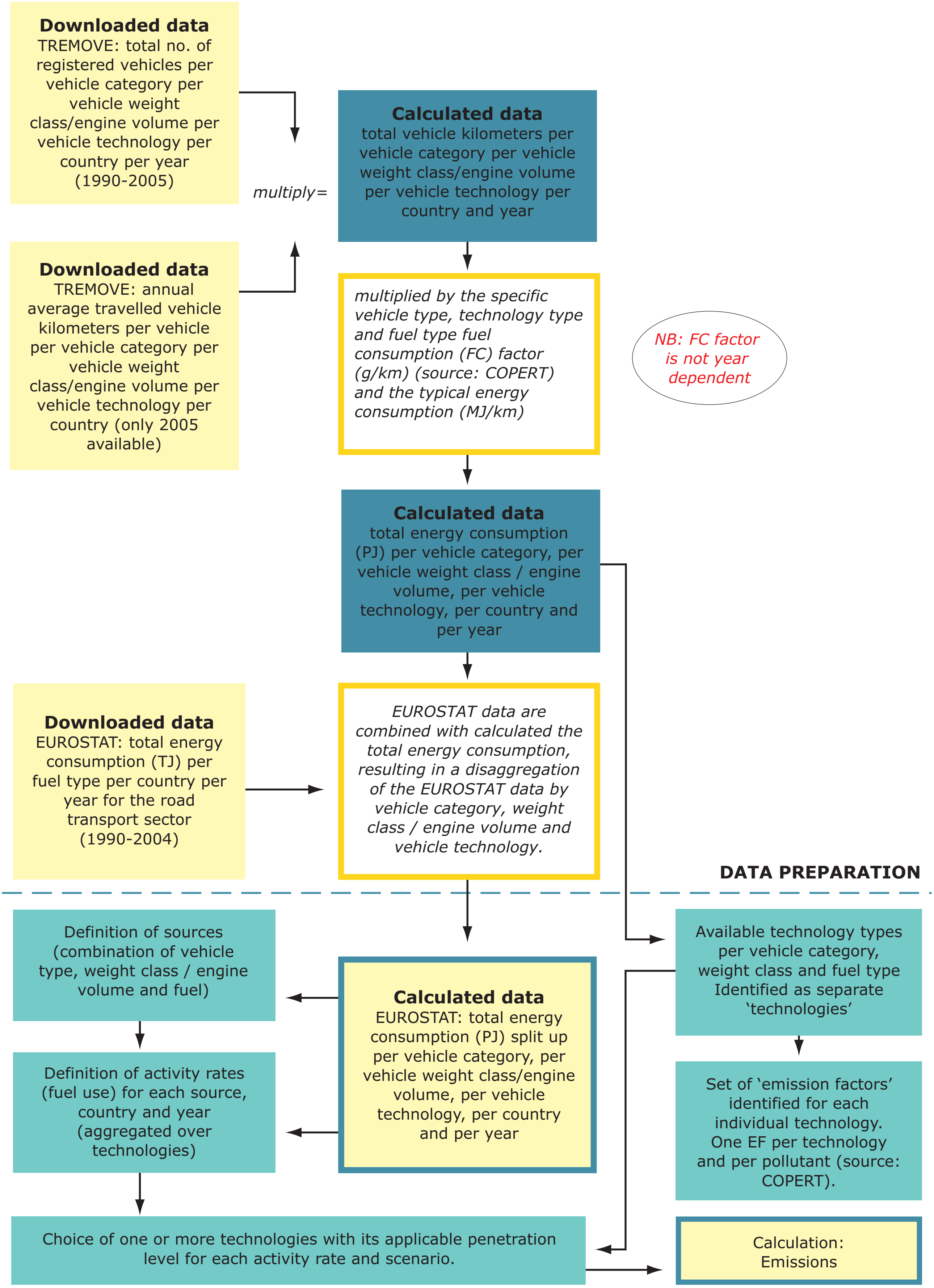
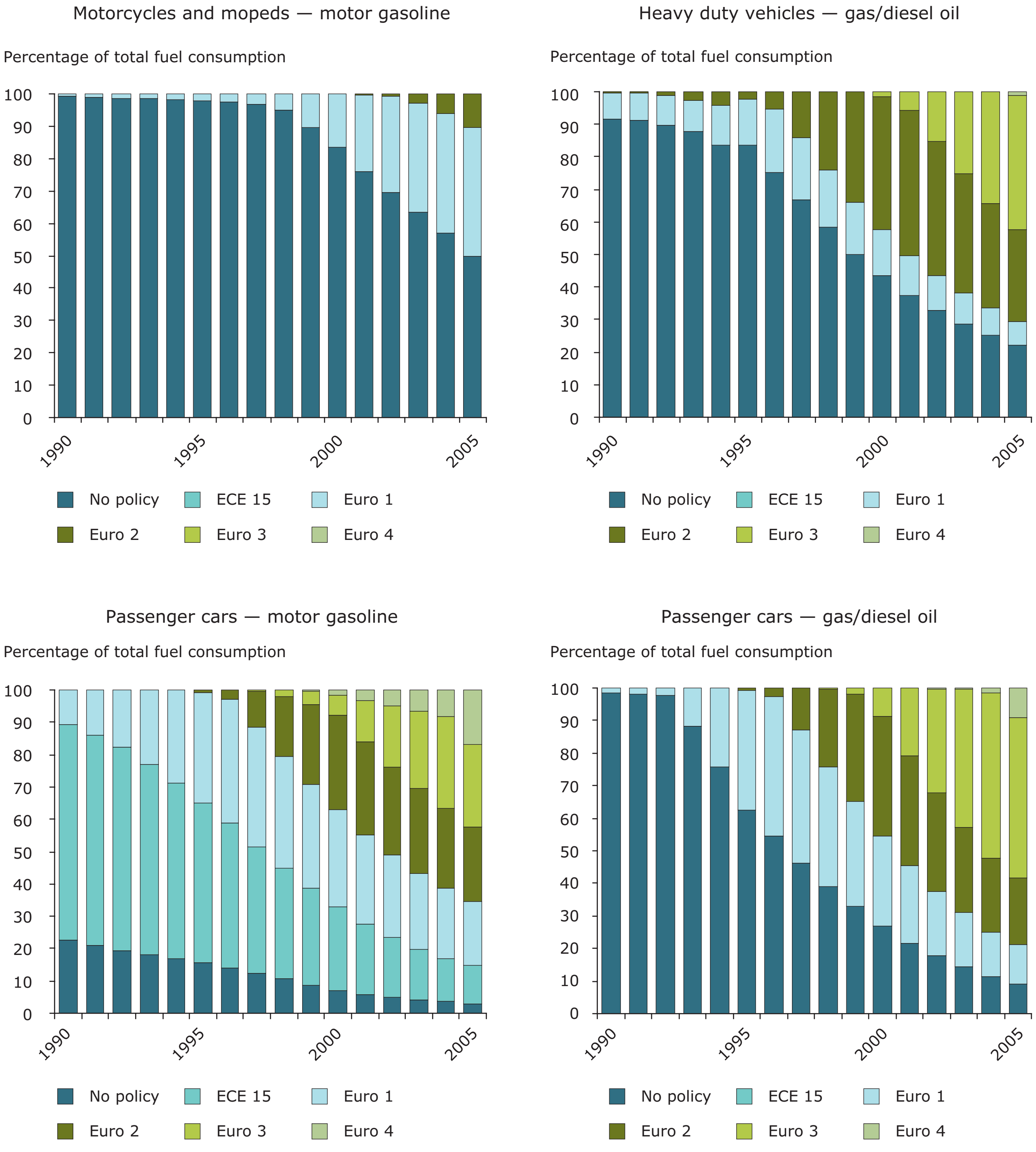


Figure 2.3 **Relative contribution of each technology type (conventional, ECE, Euro standards) to the total fuel consumption in selected vehicle types, EEA-32 countries**



Guidebook (EMEP/EEA, 2009), which provides emission factors identical to those used in the COPERT 4 road transport emission model. Annex 2 to the present report shows average emission factors per vehicle technology for selected pollutants.

2.2.2 *Industrial combustion*

Fuel consumption

Annex 3 to the present report presents an overview of the activity data used to assess abatement policies in the industrial combustion sector. Industrial combustion in this study includes:

- power plants (i.e. UNECE nomenclature for reporting (NFR) source category 1.A.1.a);
- combustion in petroleum refineries (NFR source category 1.A.1.b);
- combustion in the manufacturing industry (NFR source category 1.A.2).

Figure 2.4 provides an overview of fuel use in industrial combustion, by fuel type and industry. It shows that almost half of the fuels used in industry comprise solid fuels. The share of gaseous fuels is increasing, whereas liquid fuel use is falling. The share of 'other fuels', mainly non-fossil fuels (e.g. biomass), is small but increasing.

Power plants dominate fuel consumption in the industrial combustion sector, accounting for more than half of all fuel use and increasing over time. Refineries are relatively small energy users.

Technologies and emission factors

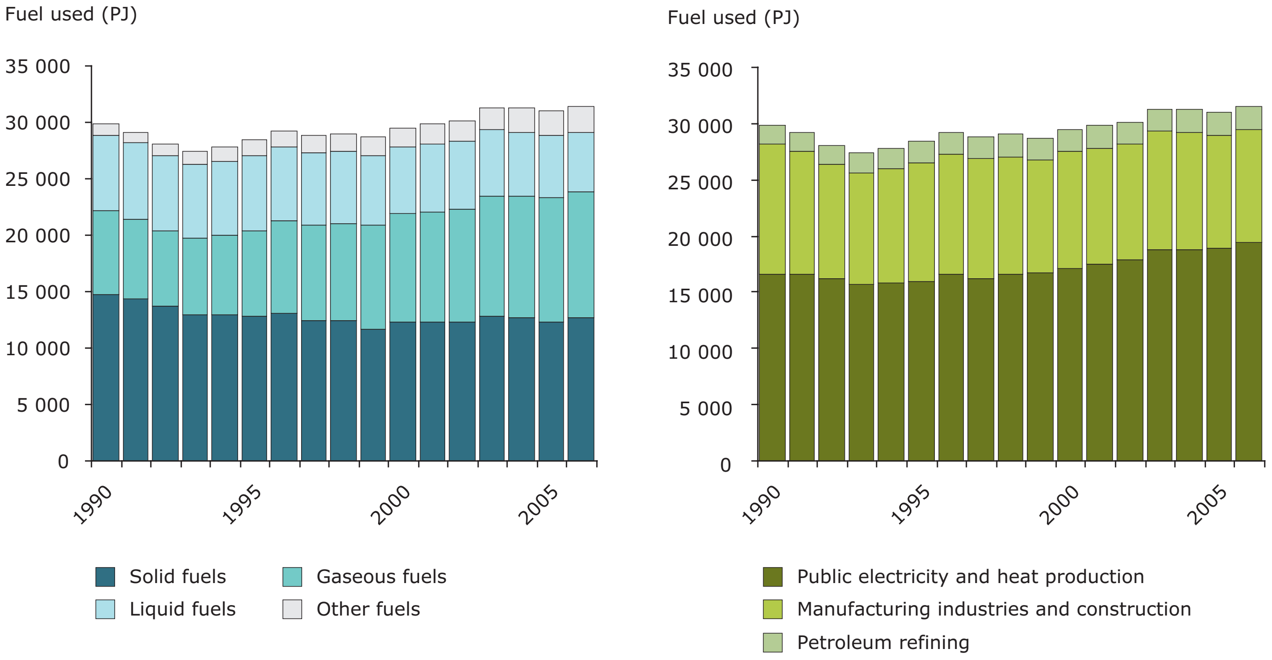
No detailed information on abatement technologies installed at individual industrial combustion installations in Europe is available through officially reported datasets from countries. Only reported emissions are generally available.

In the scenarios, emissions have only been estimated for NO_X and SO_2. Primary PM emissions are not taken into account and are assumed to be the same under each scenario (6).

Two technology scenarios have been elaborated for the industrial sector:

- the '***no application scenario***', which uses default unabated emission factors;

Figure 2.4 Activity rates for the industrial combustion sector in EEA-32 countries; left panel by fuel, right panel by industrial sector type



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(6) Note that PM emissions can be strongly affected by certain SO_2 abatement technologies such as flue gas desulphurisation)

- the '***full application scenario***', which uses emission factors based on BAT associated emission levels (AELs) fully applied in facilities (EEA, 2008b).

Unabated emission factors have been taken from the emission factors used in the GAINS-Europe online model (IIASA, 2009). The model provides emission factors per country, GAINS sector code and control measure taken.

Emission factors for the 'no application scenario'

To derive the emission factors for the unabated, '*no application*' scenario, only the emission factors with no control (NOC) were considered. These have been aggregated over countries and over the available GAINS sector codes, which lead to a number of different emission factors for both NO_X and SO_2.

For NO_X, the highest emission factor has been interpreted as the unabated emission factor for this study. In one case (liquid fuels from petroleum refining), the second highest emission factor was taken because the highest factor appears to be an outlier.

For SO_2 the situation is more complicated because the emission factor depends heavily on the sulphur content of the fuel. The highest emission factor would be in a country with a very high sulphur content in the fuels, and applying this factor as the unabated factor for all countries would result in a significant overestimation of unabated emissions. Therefore, the available emission factors have been assessed and the most appropriate emission factor (in GAINS applied for multiple countries) is selected as the unabated emission factor for this study. An overview of the derivation of the emission factors for the '*no application*' scenario is given in Annex 4 to the present report.

Emission factors for the 'full application scenario'

For the '*full application*' scenario, country-specific emission factors representing application of the LCP BREF AELs for NO_X and SO_X were obtained from a previous EEA study (EEA, 2008b). These factors are considered to represent the typical conditions in industrial facilities in a particular country. Since the earlier EEA study (2008b) only assessed emissions of NO_X and SO_X, the present analysis similarly only performs scenario calculations for these two pollutants. As the emission factors are technology dependent, they are not considered to vary with time and hence are kept constant when applying them to the annually variable activity rates reported by Eurostat when calculating emissions. Emission factors consistent with the upper BAT AELs were used in this work.

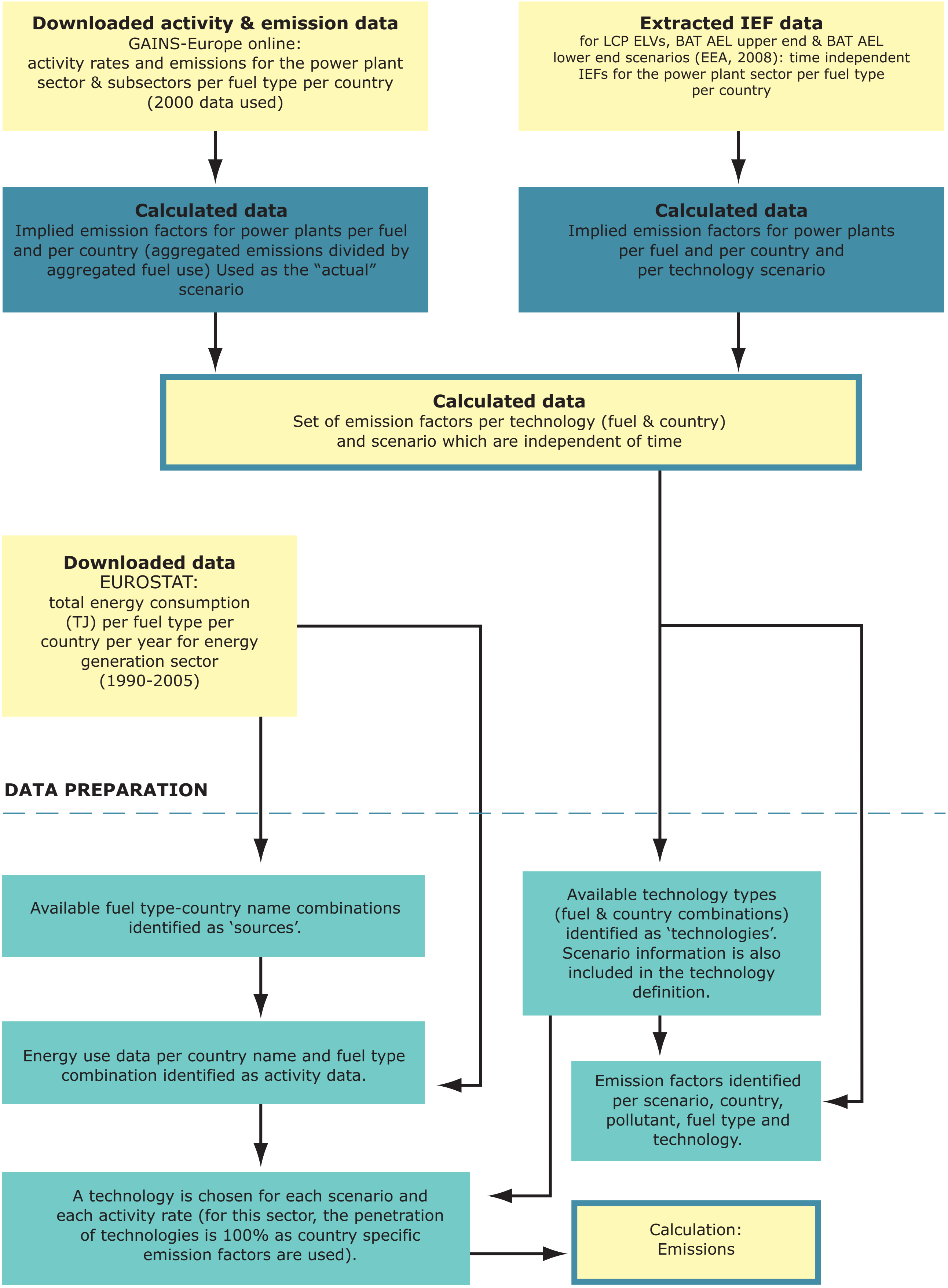
Several issues were outside the scope of the earlier EEA study (2008b) and are similarly also not addressed in the present analysis. This includes consideration of ongoing changes that have occurred in the sector since 2005 (e.g., changes to plant fuel mixes; replacement of old plants with newer, more efficient and cleaner plants; operational changes with respect to plant use such as peak or base-load generators; changes in emissions due to start-up/shut-down procedures; evolution in abatement equipment along with general economic growth).

It should also be noted that EEA (2008b), which provided the emission factors used, was based on large power plants only. In the current study, and as noted earlier, analysis is extended to the entire fossil fuel energy generation sector (i.e. including smaller power plants), as well as the petroleum refining and manufacturing industry sectors. Applying emission factors applicable to large power plants to all these sectors is a potential source of uncertainty.

In this study, 'generic' BAT (and AELs) are considered rather than unit-specific BAT. Generic BAT are the combination of non-unit-specific elements applicable to an entire industrial sector. Implied emission factors and emissions were calculated for each of the three sectors (power plants, refineries and manufacturing industry) as a whole, per fuel type and per country. This approach was adopted due to lack of data on individual facilities within Europe. For example, the extent to which BAT were applied within each facility and the period in which a specific measure was applied is not known.

Figure 2.5 presents an overview of the emission calculation procedures used in this study for the fossil fuel energy generation sector.

Figure 2.5 Methodology used to calculate emissions from the energy generation sector using the TEAM model



2.3 Air quality analysis

The effects of the policy measures under study on air quality have been assessed using the LOTOS-EUROS regional chemical transport model (Box 2.1). The model has previously been extensively validated for adequately reproducing observed air quality in Europe. In this study the model is only run for the final year in the time series (2005).

Model input data
The LOTOS-EUROS model requires emissions data at an adequate temporal and spatial resolution. The emission scenarios deliver national annual totals for road transport and industrial combustion respectively, so both a temporal and a spatial disaggregation is needed.

For other anthropogenic emission sources a European gridded emission dataset was applied, which is also available for Europe at a resolution of 0.125 ° longitude x 0.0625 ° latitude (Denier van der Gon *et al.*, 2009).

- **Temporal resolution**
  The LOTOS-EUROS model uses a temporal disaggregation function to convert annual total emission rates to hourly emission rates throughout the year. This function assumes specific temporal patterns at several scales for all sources: a day pattern to account for the 24 hours in a day; a week pattern, allowing to model weekdays and weekends; and a monthly pattern to model the seasons.

- **Spatial resolution**
  The emissions data are gridded according to the methodology of Visschedijk *et al*. (2007).

Model output data (pollutants and impact indicators)
The model produces data on hourly concentrations of a series of pollutants (NO, NO_2, NMVOCs, O_3, total PM_{10}, total $PM_{2.5}$) for the lowest atmospheric layer (up to 50 m above the ground). From these data, a series of air quality indicators may be derived:

- Gridded annual average concentrations. The annual mean PM2.5 concentrations have been used in the health impact assessment.

- Ozone impact indicators SOMO35 and AOT40:

  - SOMO35 is the sum of excess daily maximum 8-hour means above a cut-off point of 35 ppb calculated for all the days in a year. This is an indicator of exposure to ozone recommended by the World Health Organization as the most appropriate indicator to assess the impact of exposure to ozone for the total population.
  - AOT40 is an indicator that is relevant for the protection of vegetation and refers to the Accumulated Ozone exposure above a Threshold value of 40 ppb. Specifically, it is the sum of the difference between the hourly mean ozone concentrations at canopy height above 40 ppb and 40 ppb. The summation is undertaken during the relevant growing season. Thus, for crops, AOT40c is added up for the summer months of May, June and July; for forest, AOT40f is added up during the months (April–September). In both cases only daylight hours, defined as the hours between 08.00 and 20.00 CET, are included. As such the indicator takes into consideration the length of exposure and magnitude of the concentrations.

Unlike SOMO35, AOT40c is a regulatory indicator and falls under the EU Air Quality Directive (Directive 2008/50/EC). Due to complex

Box 2.1 The LOTOS-EUROS regional chemical transport model

The effects of the selected policy measures on air quality under study in this report have been assessed using the LOTOS-EUROS regional chemical transport model (Schapp et al., 2008). The model is the product of the integration of the Netherlands Organisation for Applied Scientific Research (TNO) LOTOS model and the National Institute for Public Health and the Environment (RIVM) EUROS model.

Several operational chemical transport models are currently available in Europe and have been compared for ozone and aerosols (e.g. Hass et al., 2003; Roemer et al., 2003; van Loon et al., 2004). The performance of LOTOS-EUROS is considered similar to other regional models. The LOTOS-EUROS model is able to capture the variability of ozone well, especially in summer. However, the exchange between the mixing layer and the free troposphere has been assessed to be somewhat low within the model, resulting in too high modelled ozone levels for days with low ozone. Sulphate levels are underestimated, whereas the concentrations of nitrate and ammonium are in line with measured data. The model covers the European domain (35–70 ° North, 10–60 ° East) and has a normal longitude-latitude projection.

The model runs at a temporal resolution of one hour and a spatial resolution of 0.125 ° longitude x 0.0625 ° latitude.

Box 2.2 Tropospheric (ground-level) ozone formation in the atmosphere

Ozone (O_3) is produced in the troposphere when the ozone precursors nitrogen oxides (NO_X), volatile organic compounds (VOC) and carbon monoxide (CO) react in the presence of sunlight. There are no direct anthropogenic emissions of ozone to the atmosphere. The subsequent chemical reactions involved in tropospheric ozone formation are a series of complex cycles.

Ozone formation changes under differing NO_X and VOC regimes. In conditions where there are low NO_X but high VOC concentrations, O_3 will increase if NO_X increases but remains constant if VOC concentrations increase – the so-called 'NO_X sensitive' regime. In contrast, if NO_X concentrations are high and VOC is low, O_3 will decrease with increasing NO_X concentrations but increase with increasing VOC concentrations – the 'VOC sensitive' regime.

The rate of O_3 formation is strongly dependent upon meteorological conditions and particularly sunlight. Ozone episodes, periods of high O_3 concentrations, are likely to develop following sustained periods of warmth and calm weather. Once formed, O_3 can be scavenged and removed from the atmosphere by nitric oxide (NO) present as a result of traffic fumes. Consequently, O_3 usually occurs in higher concentrations during summer than winter, and in rural rather than urban areas (where traffic levels and hence NO concentrations are higher).

non-linearities in the atmospheric chemistry of ozone and its precursors (see Box 2.2), lower emissions of specific ozone precursors may actually yield higher ozone concentrations in some areas.

2.4 Impact assessments

2.4.1 *Human health*

The concentration maps calculated for each of the emission scenarios are used as input for a health impact assessment. The impact assessment is made with the same grid resolution as the dispersion model. It is assumed that the population within a grid cell is exposed to the same grid cell averaged concentration. Concentration gradients within a cell, differences in exposure for different population classes and indoor pollution have not been included in the assessment.

For quantifying the effect of air pollution, the relative risk (RR) in a population whose exposure is estimated by an average concentration C is given by the concentration-response function:

$$RR = \exp\left[B\left(C - C_0\right)\right]$$

where C_0 is a reference concentration (the background concentration that would exist without any man-made pollution determined by natural sources or a concentration below which no health effects are to be expected). *B* is the estimated effect of the pollutant on the health outcome (e.g. mortality from cardiopulmonary diseases) and is given as an increase in incidence per unit increase in concentration (see Table 2.1). In the assessment presented below the reference concentration C_0 is set to zero.

Once the relative risks have been determined, the attributable fraction (AF) of a specific health effect from air pollution for the exposed population is:

$$AF = \sum P_i\left(RR_i - 1\right) / \sum P_i RR_i$$

where P_i = the proportion of the population at exposure category i

RR_i = the relative risk in exposure category i

When the total population is considered with only one exposure level, this simplifies to:

$$AF = \left(RR - 1\right) / RR$$

The expected total number of cases of premature mortality due to air pollution is given by:

$$E = AF \cdot MR \cdot Pop$$

where E = the expected number of deaths due to outdoor air pollution

RR_i = the population incidence of the given health effect (i.e. cases per 1 000 people per year)

Pop = the relevant exposed population for the health effect. Here only the proportion of the population aged 30 years or older has been considered

Table 2.1 Mortality relative risk associated with a 10 μg/m³ change in $PM_{2.5}$ and ozone concentration

Health outcome ([a])	**Relative risk per 10 μg/m³ (95 % CL)**
$PM_{2.5}$, Mortality from cardiopulmonary disease, adults > 30 year	1.08 (1.02–1.14)
$PM_{2.5}$, Mortality for lung cancer, adults > 30 year	1.13 (1.04–1.22)
$PM_{2.5}$, Total mortality, adults > 30 year;	1.06 (1.02–1.10)
Ozone, Total mortality, adults > 30 year	1.003 (1.001–1.004)

Note: ([a]) In all cases baseline incidences have been estimated excluding violent deaths.

Source: Pope et al., 2002; WHO, 2006.

National demographic data (absolute numbers, age/sex distributions) for 2005 have been taken either directly or after downscaling from international regional level to national level using World Population Prospects data (UNDESA, 2004). Similar age distributions for each grid cell within a country are assumed. Information on country-specific baseline incidences is obtained from the WHO Burden of Disease project (WHO, 2004; Mathers and Loncar, 2006). Mortality Risk (MR) is estimated using age- and sex-dependent baseline incidences. In this study health outcomes are presented as years of life lost (YOLL).

At the ambient levels currently observed over Europe, the health impacts attributable to exposure to $PM_{2.5}$ are an order of magnitude larger than the impacts attributable to ozone exposure. It might be that in the current estimates the impact of ozone is underestimated: only short-term exposure is accounted for while there are indications that long-term exposure to lower levels of ozone also has a strong health impact.

2.4.2 Ecosystems

The assessment of impacts on vegetation and ecosystems has been limited to estimation of the fractions exposed to AOT40 levels above the long-term objective, target or critical level set. In the Air Quality Directive a target value (TV) and long-term objective LTO) have been set for the protection of vegetation. The target value (to be met by 2010) is 18 000 μg/m^{-3}.h; the LTO is set as 6 000 μg/m^{-3}.h.

The term '*vegetation'* is not further defined in the Ozone Directive. Comparing the definitions in the UNECE Mapping Manual (UNECE, 2004) and those in the Ozone Directive, one interpretation is to assume the term *vegetation* in the ozone directive means agricultural crops. The exposure of *agricultural crops in this study* has been evaluated by combining the ozone concentration maps with the Corine Land Cover map. Agricultural crops are defined here as Corine Land Cover level 1, class *2, Agricultural areas* (encompassing the level 2 classes *2.1 Arable land, 2.2 Permanent crops, 2.3 Pastures and 2.4 Heterogeneous agricultural areas)*.

The UNECE LRTAP Convention defines a critical level for protecting forest: 10 000 μg/m^{-3}.h (corresponding to 5 ppm.h), based on an accumulation over the full vegetation period, April–September. In the present study, forest areas are defined as Corine Land Cover level 2, classes *3.1 Forests* and *3.2 Scrub and/or herbaceous vegetation associations.*

3 Achievements of European air emission policies

3.1 Emission reductions in road transport

3.1.1 *Drivers: energy use in road transport*

As shown in Figure 3.1, energy use in road transport has increased over the 15 years time span covered in the present study. Figure 3.1 compares the growth in energy demand for transport with population and economic growth, addressing passenger and freight transport separately.

The following key points can be noted:

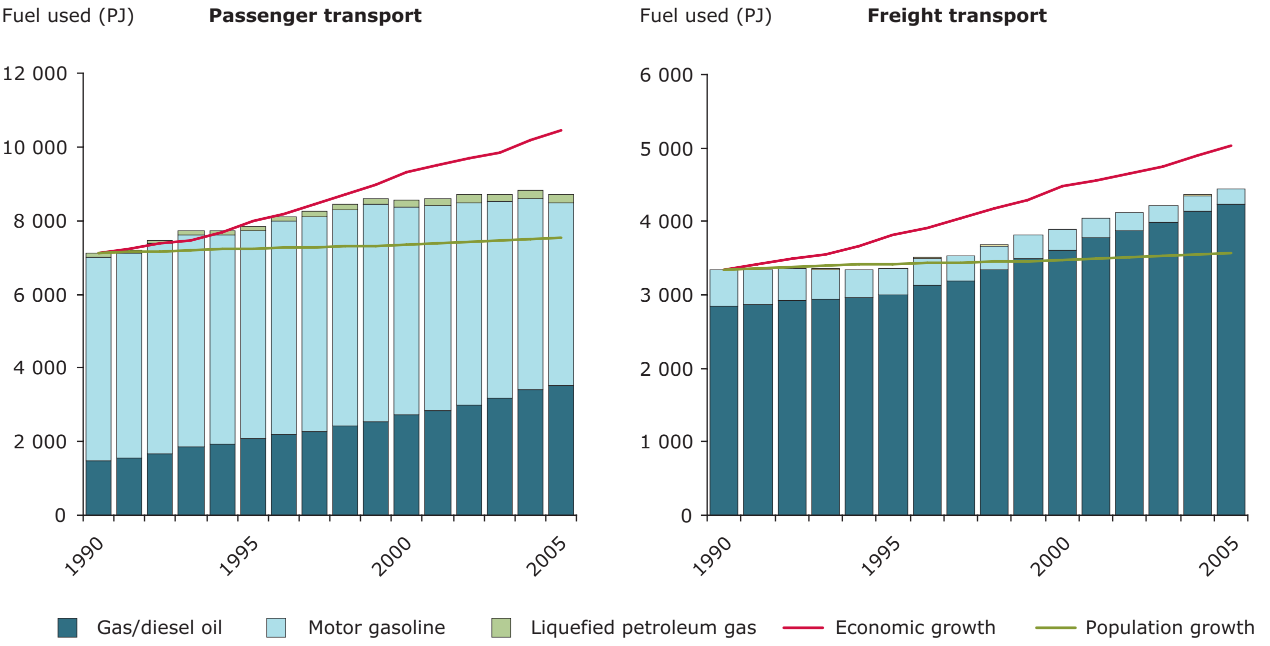
- Energy use in passenger transport grew in parallel with economic growth (GDP) until the mid-1990s. After that point the growth in energy use levelled off and now more closely follows the lower growth rate of population size.
- Fuel use in freight transport shows the opposite trend. In the first half of the time series energy grows only marginally, whereas since the mid-1990s energy use seems to follow economic growth.

These findings are consistent with earlier EEA analysis (EEA, 2009).

On the whole, analysis shows that energy consumption in the road transport sector increased by approximately 20 % during the period 1990–2005.

Consumption of diesel doubled between 1990 and 2005, whereas the consumption of gasoline slightly decreased over time. The use of LPG has increased over time, but still forms a negligible share in the total fuel consumption balance.

Figure 3.1 Growth in transport energy use in the EEA-32 countries, compared to trends had energy use followed population growth and economic growth (GDP)

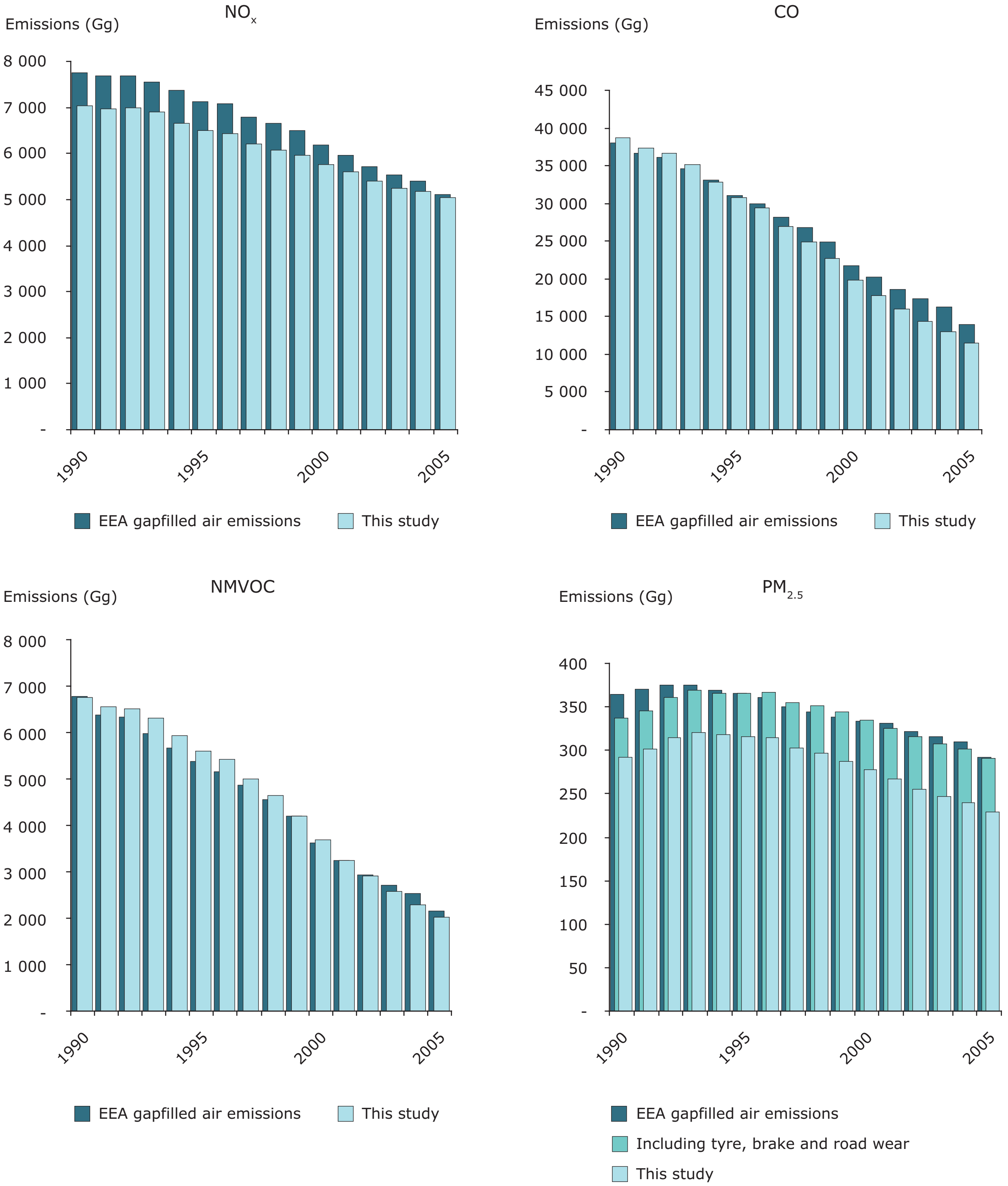


3.1.2 Pressures: emissions from road transport

Past emissions

Figure 3.2 presents the reconstructed actual emissions of main pollutants by road transport in the EEA-32 countries between 1990 and 2005, estimated using the TEAM model. The estimates are compared with the emissions reported by countries (EEA, 2008a). The following points can be noted:

Figure 3.2 **Comparison of road transport emissions (from all fuels) estimated in this study and officially reported gap-filled air emission data from EEA-32 countries**



Source: EEA, 2008a.

- There is a very good agreement between the modelled and country-reported emission levels for CO and NMVOC. The TEAM model slightly underestimated NO_X emissions in the first half of the study period. However, the agreement in modelled and reported emissions in the latter half of the study period is again considered very acceptable. The underestimation at the beginning of the study period can be attributed to lower NO_X emission factors for older vehicle technologies (pre-ECE) compared to those applied by the individual countries when reporting their emissions for this period.

- The TEAM model seems to underestimate the $PM_{2.5}$ emissions throughout the entire study period. This difference may be attributed to the fact that $PM_{2.5}$ emissions from tyre, brake and road wear were not included in the TEAM calculations (but are included in national reported road transport emission estimates). In order to verify this explanation for the model's underestimations, $PM_{2.5}$ emissions from tyre, brake and road-wear were separately calculated by multiplying the vehicle kilometres travelled by the respective emission factors for tyre, brake and road wear as reported in the EMEP/EEA Air Pollutant Emissions Guidebook (EMEP/EEA, 2009). This combined dataset (shown as a separate column in the $PM_{2.5}$ diagram in Figure 3.2) leads to much better agreement with the emissions reported by countries and hence shows that tyre, brake and road wear may indeed be considered the missing $PM_{2.5}$ sources in the initial emission calculations. Just as for NO_X, however, during the first years of the study period the combined dataset underestimated emissions compared to countries' officially reported data. In the case of PM, this could be attributed to the relatively high uncertainty in the emission factors used for PM, especially for older vehicles (Ntziachristos, 2008). The $PM_{2.5}$ emissions from road, tyre and brake wear were calculated only to confirm verification of TEAM-modelled emissions with country-reported emissions data. The road, tyre and brake wear source has further not been considered in the current study.

All in all, a general decrease in pollutant emissions from the road transport sector is evident in the EEA-32 countries between 1990 and 2005 (Figure 3.2) and seems to be adequately modelled using the TEAM approach.

Figure 3.3 presents the contribution of vehicles compliant with each Euro standard to total annual emissions within the study period. The results show that 'no-policy' vehicles still contribute significantly to emissions of each pollutant (accounting for *ca.* 20 % of NO_X emissions; 30 % of CO emissions; and 40 % of NMVOC and $PM_{2.5}$ emissions in 2005). This share has declined with time for NO_X and PM, while for CO and NMVOC the decrease is relatively small. Since the emission factors for 'no policy' vehicles are high relative to those for vehicles compliant with Euro legislation, their contribution to the total emissions of the entire vehicle fleet per country is also relatively high.

The contribution of the different road transport fuels to the emissions of air pollutants is shown in Figure 3.4. Emissions of primary particulate matter are mainly due to diesel-fuelled vehicles, whereas emissions of CO and NMVOC are primarily caused by gasoline vehicles. The picture for NO_X appears rather more complicated. The large contribution from gasoline-fuelled cars in the early 1990s is decreasing over time due to the introduction of catalytic converters.

The effect of European road transport legislation on air pollutant emissions

Overall, Euro vehicle emissions of NO_X, $PM_{2.5}$, CO and NMVOC have fallen significantly over time (Figures 3.2 and 3.3). The present section assesses the contribution of European road transport abatement policies to this decrease.

Figure 3.5 compares the reconstructed emissions of NO_X, CO, NMVOC and $PM_{2.5}$ derived from Figure 3.2 (the '*actual*' scenario) with those that would have occurred if:

- all vehicles were equipped with unabated technologies (listed as 'conventional' technologies in Annex 2) throughout the study period – the '*no application*' scenario.;
- all vehicles were fully equipped with the Euro 4 technology – the '*full application*' scenario.

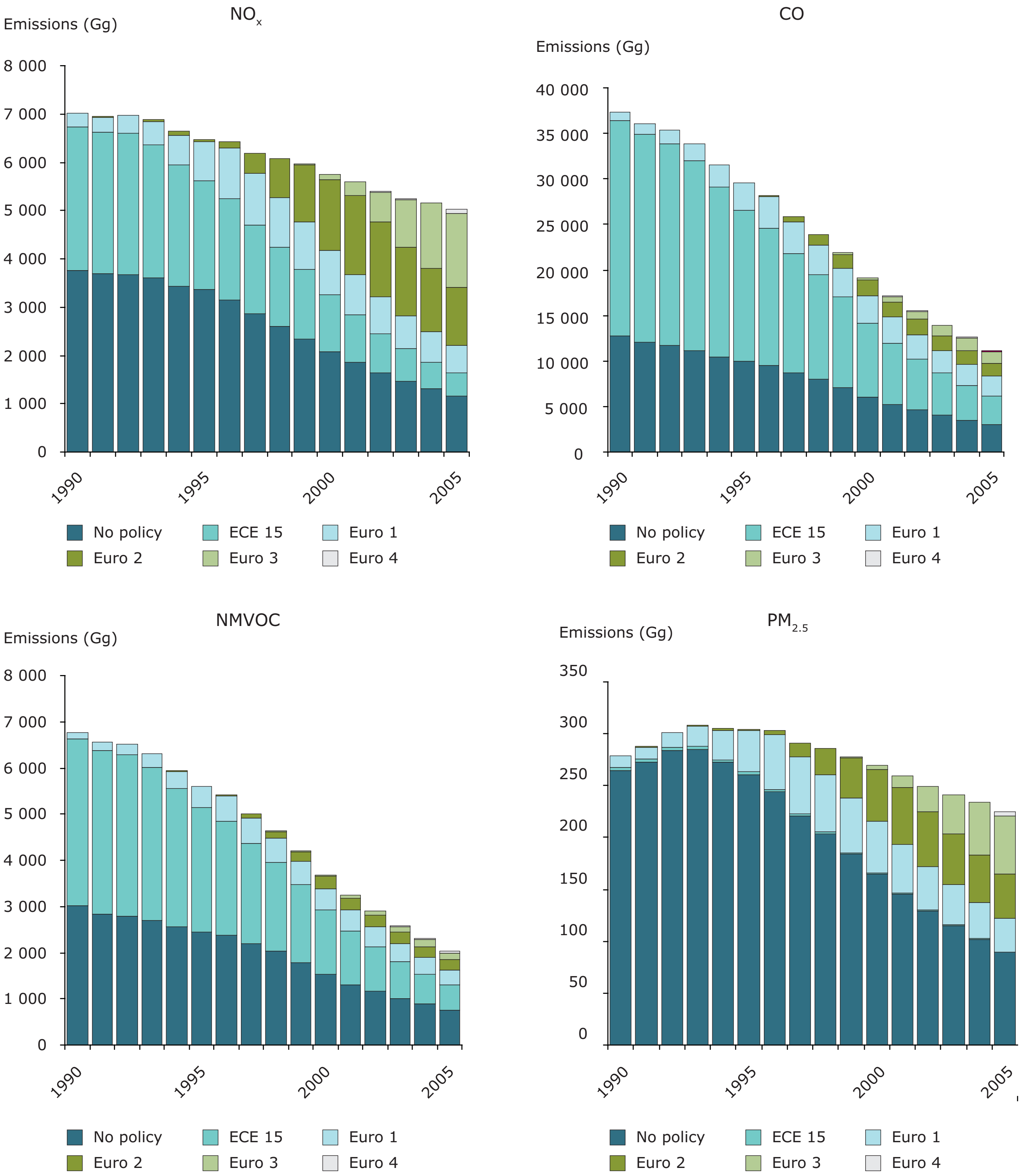
The analysis show the effect of the introduction of the abatement measures (the difference between the red and blue columns) and the remaining potential of these measures within the existing car fleet (the difference between the blue and green columns).

The following observations are noteworthy:

- by 1990, ECE-15 standards had already reduced NO_X and NMVOC emissions significantly compared to the '*no application*' scenario;

- the introduction of European road vehicle standards has markedly decreased emissions of various air pollutants:
- NO_X emissions in 2005 were 40 % below the *'no application'* scenario, and would have been 20 % lower still if all vehicles had theoretically been equipped to the Euro 4 standards;
- the exhaust emissions of CO and NMVOC were 80 % and 68 % respectively below unabated levels and could have been 93 % and 90 % respectively at full implementation of Euro 4 technology;

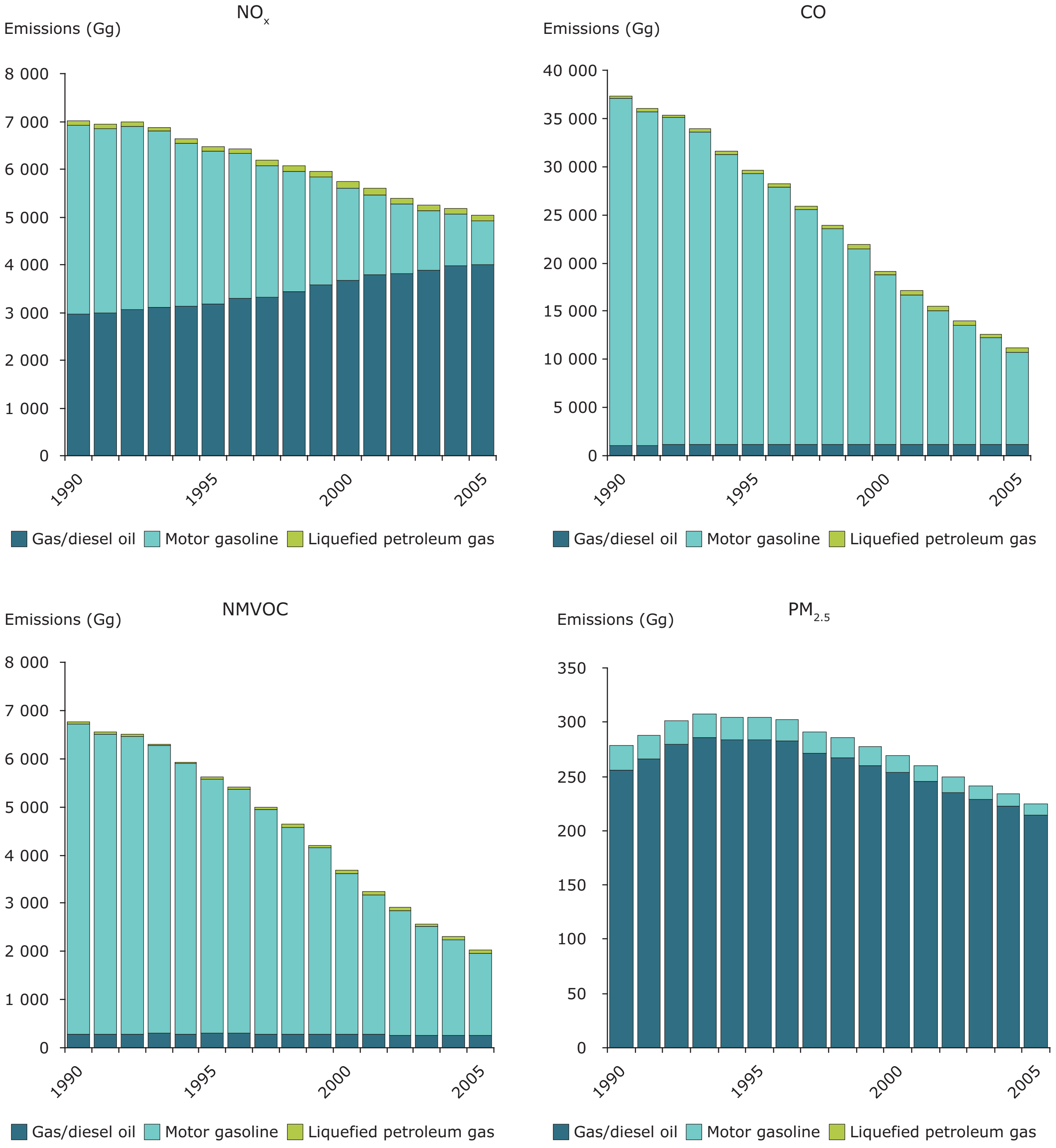
Figure 3.3 **Contribution of different technology types to total exhaust emissions of NO_x, CO, NMVOC and $PM_{2.5}$ in EEA-32 countries (*'actual'* scenario); emissions are aggregated over all road transport vehicle types and fuels**



- exhaust emissions of fine particulate matter ($PM_{2.5}$) were 60 % below unabated levels and full implementation of Euro 4 technology would have resulted in a reduction of 83 % for this pollutant.

It is understandable that the Euro legislation has not been able to tackle all pollutants equally across all vehicle types. Different approaches are needed to combat emissions in gasoline-powered vehicles in comparison to diesel-powered ones.

Figure 3.4 **Contribution of different fuel types to total exhaust emissions of NO_x, CO, NMVOC and $PM_{2.5}$ in EEA-32 countries (*'actual'* scenario); emissions are aggregated over all road transport vehicle types and technologies**



Catalytic converters

The catalytic converters used today in spark-ignited gasoline vehicles are responsible for major reductions in exhaust emissions of CO, NMVOC, and NO_X. However, these catalysts do not work on diesel engines, which operate on lean fuel-to-air mixtures. Due to the leanness of the air-fuel mixture, exhaust gases from diesel engines contain an excessive amount of oxygen, which inhibits the chemical reduction of NO_X to nitrogen, rendering the typical catalytic converters useless for NO_X removal in diesel-powered vehicles (Westbrook, 2008). Currently, lean-burn engines such as the diesel engine are the focus of most engine research today because they offer a better fuel economy than any other commercially viable engine.

Diesel vehicles

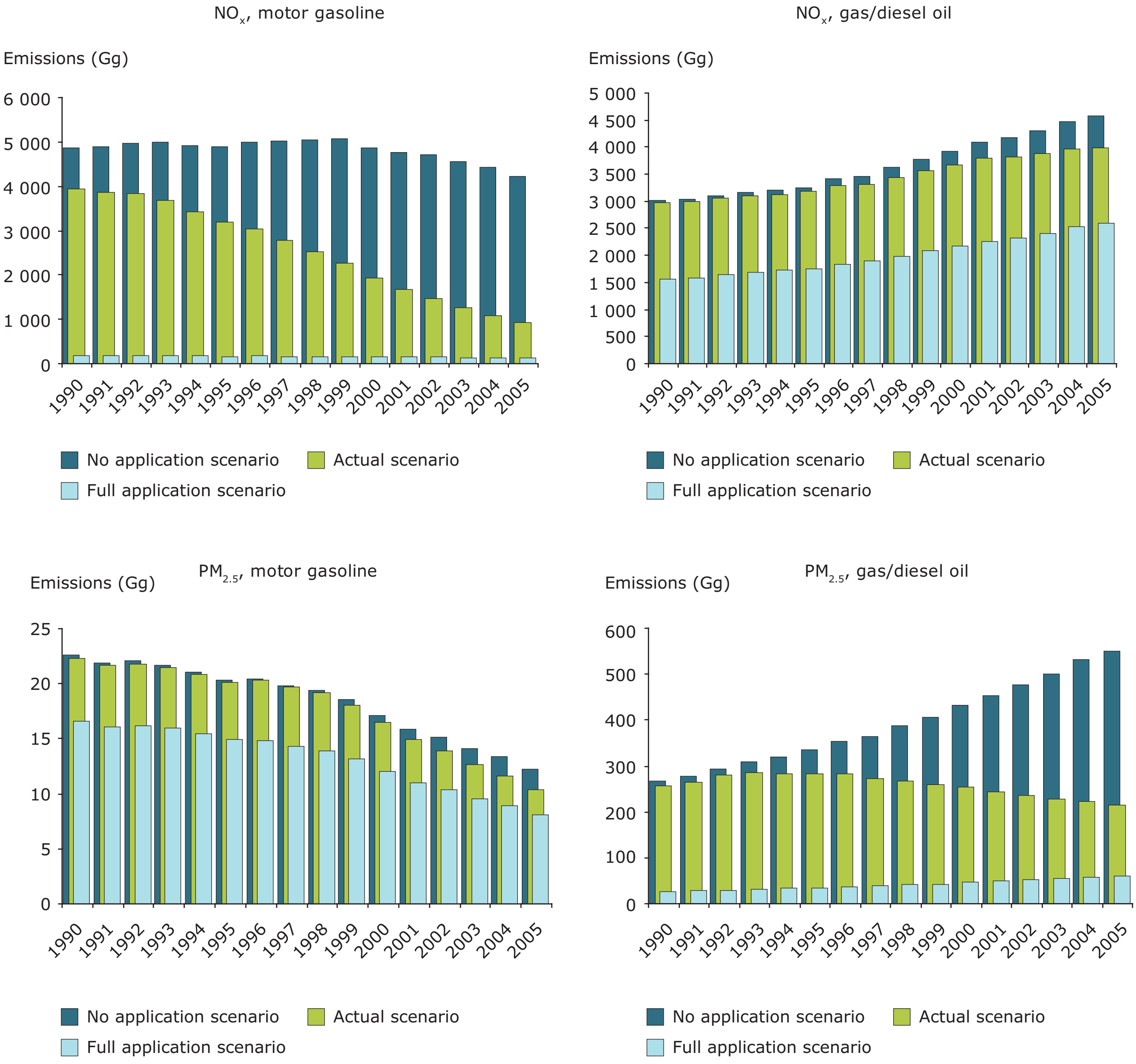
Diesel-fuelled vehicles are the major source of (primary) particulate matter (Figure 3.4). The introduction of Euro standards therefore had hardly

Figure 3.5 **Comparison of emissions for road vehicles in EEA-32 countries for the '*no application*', '*actual*', and '*full application*' scenarios— aggregated data for all fuel types**

any effect on the particulate matter emissions from gasoline-fuelled vehicles. Figure 3.6 shows that these abatement policies had a considerable effect on the exhaust emissions of $PM_{2.5}$ from diesel-fuelled vehicles.

The challenge of simultaneously tackling emissions of all pollutants is universal to all internal combustion engines and not unique to diesel-fuelled vehicles. Greater engine efficiency (i.e. optimised combustion) reduces exhaust emissions of CO, NMVOC and primary PM emissions (which are products of incomplete combustion) but increases the emission of NO_X (which is best formed at high temperatures and with high oxygen availability). If the combustion process is modified to reduce NO_X emissions, larger amounts of NMVOC, CO and $PM_{2.5}$ are emitted.

Figure 3.6 Comparison of emissions by fuel type of selected pollutants for road vehicles in EEA-32 countries for the '*no application*', '*actual*', and '*full application*' scenarios



NO_x, motor gasoline

NO_x, gas/diesel oil

$PM_{2.5}$, motor gasoline

$PM_{2.5}$, gas/diesel oil

3.2 Emission reductions in industrial combustion

3.2.1 *Drivers: energy use in industrial combustion*

The trend in energy use 1990-2005 by industrial combustion plants (including refineries and combustion in the manufacturing industry and construction sectors) is given in Figure 2.4 previously, both per fuel and per sector.

The main fuels used in large combustion installations are solid and gaseous fuels, with use of solid fuels decreasing with time and the use of gaseous fuels increasing. The importance of liquid fuels decreased slightly during the study period. The share of biomass increased between 1990 and 2005, but remains relatively small.

In terms of sectoral energy use, public electricity and heat production (power plants) accounts for the largest share of total fuel use in industrial combustion and increased slightly during the study period. The share of fuel consumed in petroleum refineries is increased slightly, while the fuel consumed in the manufacturing industry decreased.

Overall, the fuel consumed by large combustion installations decreased in the first few years of the study period (1990–1993) and increased thereafter 2005. Total primary energy consumption in 2005 was slightly higher than in 1990.

An overview of energy consumption per fuel type in the fossil fuel energy generation (power plants) sector as a whole is given in Figure 3.7. The figure shows that the major fuel types consumed in fossil fuel power plants are hard coal, lignite, natural gas and residual fuel oil. The share of hard coal is fairly constant, while the share of brown coal decreased slightly during the study period. The use of liquid fuel (oil) in power plants almost halved during the study period, while the use of natural gas in the sector more than doubled. Additionally, the share of biomass and waste increased. Overall, a slight increase in the use of fossil fuels is observed between 1990 and 2005. The choice of fuel types used is greatly determined by fuel price and installed technology types. Figure 3.7 also presents the final electricity consumption by all sectors (households, commerce, transport and industry) (Eurostat (indicator 101700).

In general, power plants have become more energy efficient over time. This can be partly attributed to the increased use of natural gas power plants, which are generally more energy efficient than power plants fired by other fossil fuels. The remainder of the difference between total energy consumption and the energy produced from fossil fuels is attributed to the increasing share of non-fossil fuel energy use (e.g. wind, solar and nuclear energy) in EEA-32 countries.

3.2.2 *Pressures: emissions from industrial combustion plants*

The (aggregated) officially reported emissions by countries under the UNECE LRTAP Convention in NFR source categories 1.A.1 (Combustion in Energy Industries) and 1.A.2 (Combustion in Manufacturing Industries) are used as the estimate for actual emissions from industrial combustion plants throughout the time span of this study (EEA, 2008a).

The activity data presented in Figure 3.7 can be used to estimate emissions in the *'no application'* and *'full application'* scenarios. Figure 3.8 presents the 1990 and 2005 emissions from each EEA member country together with the emissions under the *'no application'* and '*full application*' scenarios estimated using the TEAM model.

The following points may be observed:

- For most countries reported NO_X emissions are within the range between the *'no application'* and *'full application'* estimates, both in 1990 and in 2005.
- For SO_2, some reported emissions in 1990 (and to a lesser extent in 2005) are significantly above the *'no application'* estimate produced by the TEAM model. This suggests that the sulphur contents in these countries may be considerably higher than the sulphur contents implicitly assumed in the unabated emission factors used.
- Comparison of the 1990 and 2005 estimates shows that for many countries the reported emissions move downwards over time within the range spanned by the *'no application'* and *'full application'* scenarios.

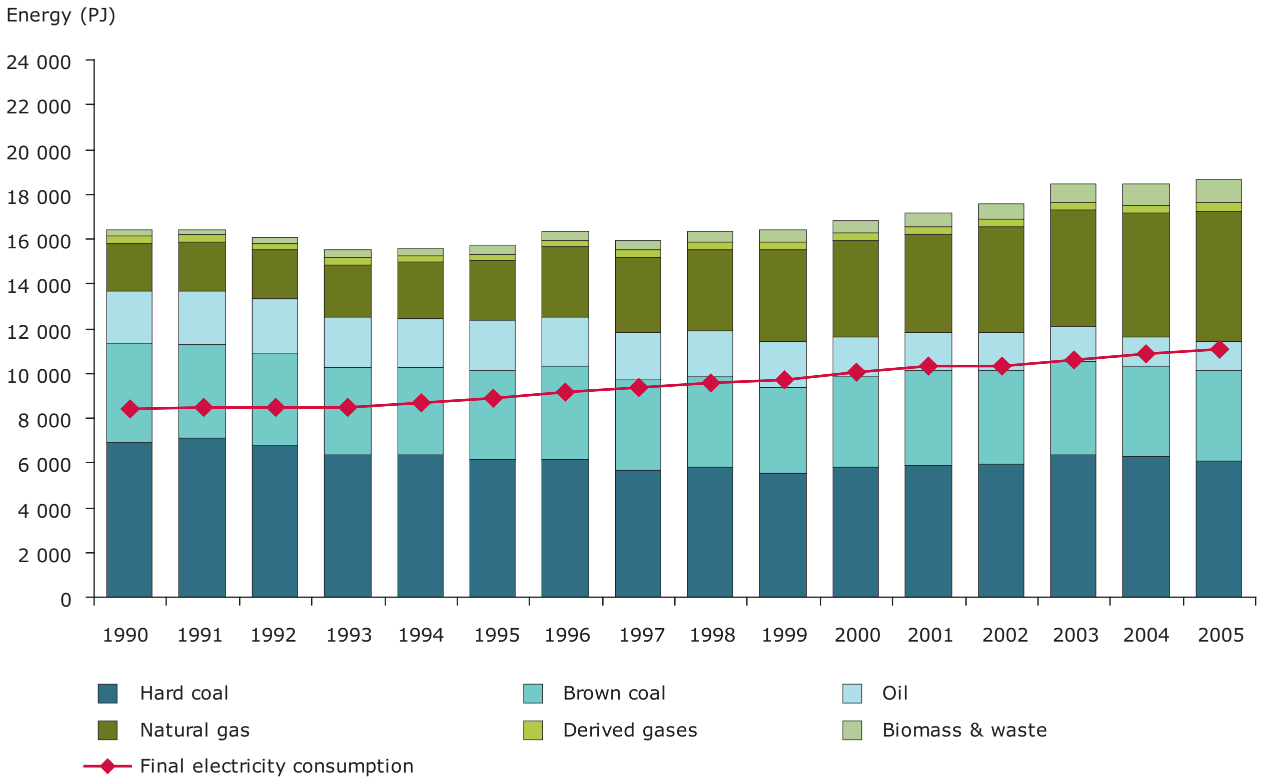
The findings presented in Figure 3.8 show that the estimates of both the *'no application'* and *'full application'* emissions of NO_X and SO_2 are generally consistent with the emissions reported by individual countries. This being the case, a time series of the industrial combustion plant emissions can be constructed, similar to that for road transport (Figure 3.5). The result is shown in Figure 3.9.

Figure 3.9 clearly shows that in 1990 the actual emissions of both NO_X and SO_2 from industrial combustion plants were already significantly below the '*no application*' level, despite the LCP/IPPC Directives not being introduced until after this date. This of course reflects the fact that many European countries had already implemented some measures to abate air pollutant emissions, including acidifying emissions, during the 1970s and 1980s.

Between 1990 and 2000 a further decrease in NO_X emissions is attributed to the gradual implementation of abatement technologies. The unabated emissions also decreased over this period in time, albeit at a much slower rate, presumably mainly as a result of a shift towards less polluting natural gas. The reported NO_X emissions do not really exhibit any further reduction since around year 2000.

Figure 3.9 also shows that by the end of the study period, application of the BAT associated AELs of the LCP BREF in all industrial combustion plants would have decreased the NO_X emissions from these source categories by half and those of SO_2 by almost two-thirds. This result is consistent with the earlier conclusions on the theoretical potential of implementation BAT associated AELs in European power plants (EEA, 2008b). As the present study employs different datasets and methodologies, the consistency of the findings helps contribute to the verification of both analyses.

Figure 3.7 Fuel consumption trends in the energy generation sector in EEA-32 countries, and growth in final electricity consumption by all sectors (households, commerce, transport and industry)



Source: Eurostat.

Figure 3.8 Reported emissions of NO_x and SO_2 in 1990 and 2005 for EEA member countries together with estimated emissions under the *'no application'* and *'full application'* scenarios

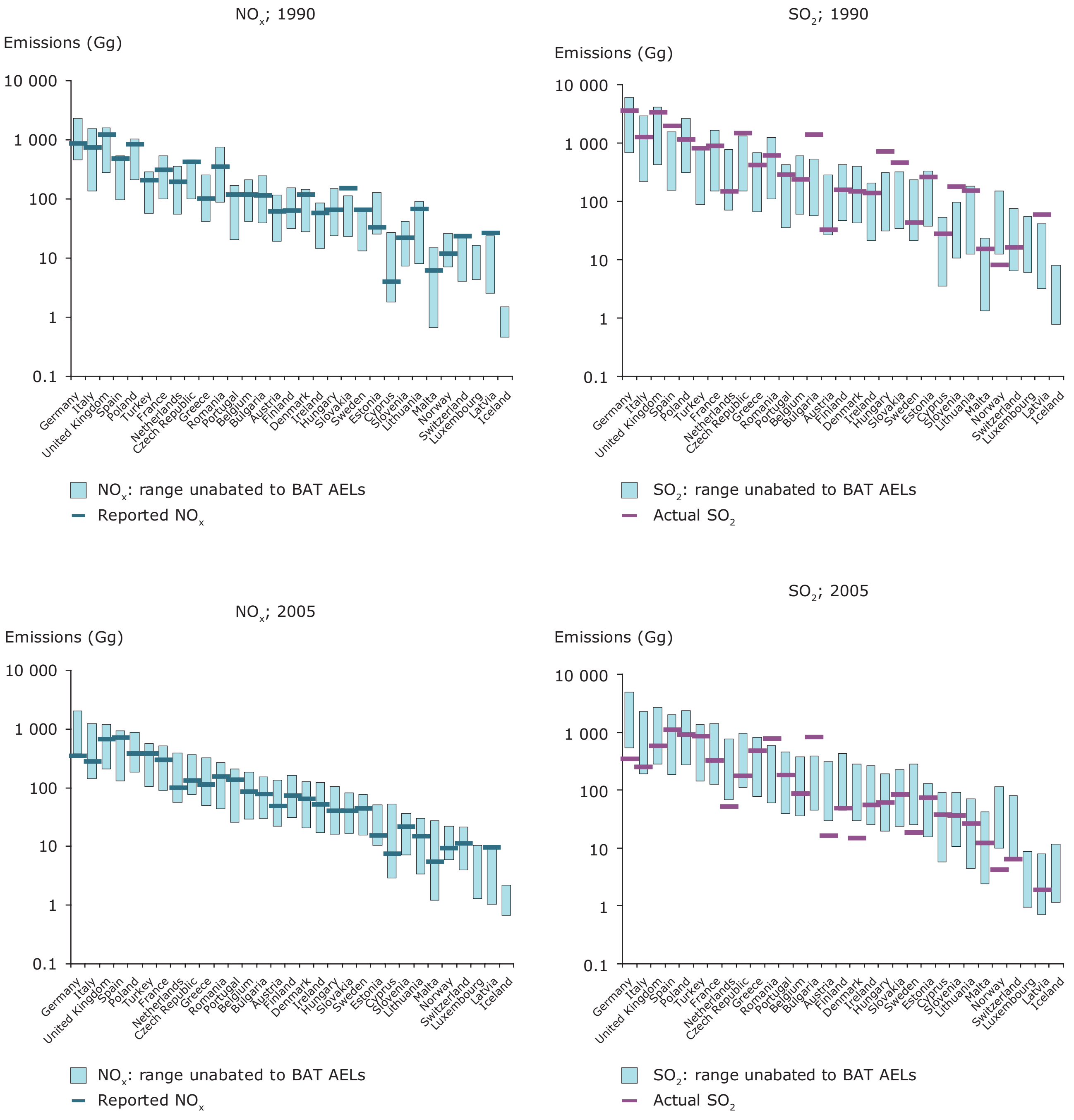
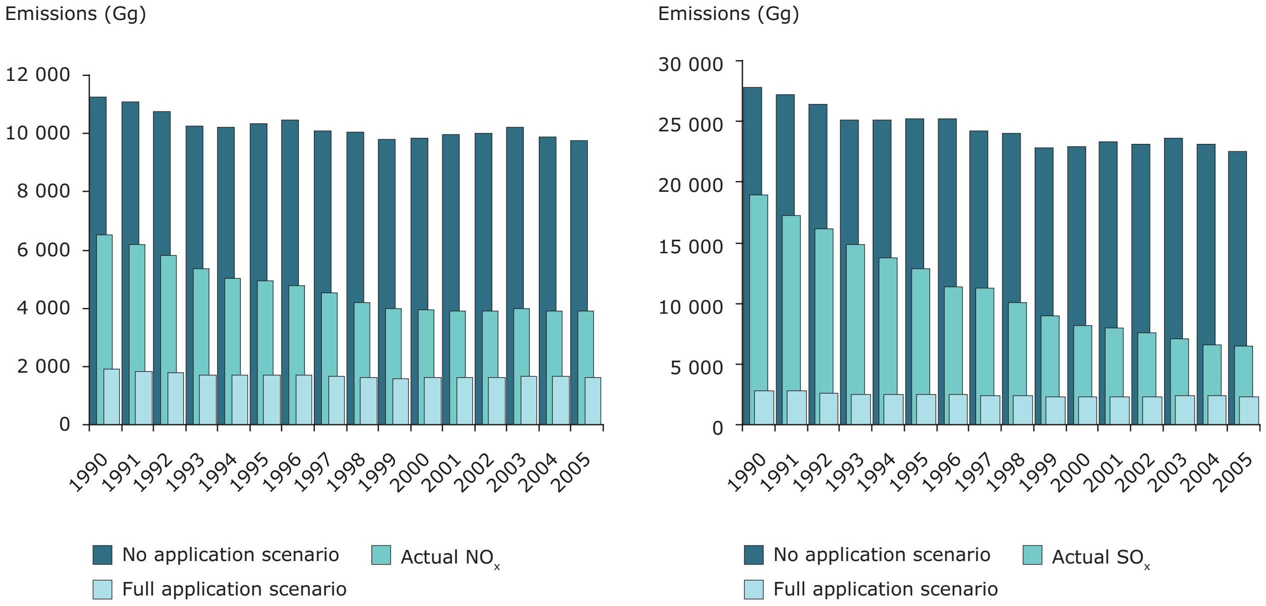


Figure 3.9 **Comparison of the '*no application*', '*actual*' and '*full application*' scenarios for industrial combustion plants (EEA-32 countries) for NO$_x$ (left) and SO$_x$ (right)**



3.3 Did air quality improve?

3.3.1 Ambient air concentrations

As previously noted, road transport contributes significantly to emissions of both tropospheric ozone precursors and fine particulate matter, whereas large industrial combustion contributes significantly to both fine particulate matter and acidification. The present section provides concentration maps for the three air pollution issues generated using the LOTOS-EUROS model, based on the modelled actual emissions from road transport; the nationally reported emissions from large industrial combustion; and the remaining 'other sources' in EEA-32 member countries.

Acidification

NO_2 and SO_2 are the two main components contributing to acidification. The concentrations calculated using the *'actual'* scenario are shown in Figure 3.10.

Calculated concentrations of NO_2 vary from below 0.5 to around 30 ppb. The highest concentrations are found in the region between London and the German Ruhr area and in other major cities and urban areas such as Manchester and Liverpool, the Po Valley and Moscow. For SO_2, highest values are typically found in industrial areas in eastern Europe.

Fine particulate matter

Total fine particulate matter concentrations in 2005 are shown in Figure 3.11. These concentrations include both the primary emitted $PM_{2.5}$ as estimated in the 'actual scenarios' above and the secondary particulate matter formed in the photochemical reactions in the atmosphere from mainly nitrogen oxides, sulphur oxides and ammonia. Emissions from non-road transport source categories are those officially-reported by countries for 2005.

Calculated concentrations of fine particulate matter in Europe in 2005 vary between 5 $\mu g/m^3$ and more than 20 $\mu g/m^3$. The highest concentrations occur in the industrialised areas of the Low Countries and the Po Valley. Elevated levels of particulate matter are also shown in the industrialised areas in Central Europe.

Compared to the European maps prepared by de Leeuw and Horalek (2009) using a combination of modelling and monitoring data, the EURO-LOTOS regional model tends to underestimate the $PM_{2.5}$ concentrations. Also when compared to the observations at rural background stations available from AirBase (2010) an underestimation is noted. This might be caused by underestimation of the primary emissions (e.g. re-suspension of road dust, see also the discussion in Section 3.1.2) and/or by underestimating the forming of secondary aerosols, in particular from (biogenic) VOC. As the present study compares modelled concentrations in a reference

Figure 3.10 **Calculated annual mean ambient concentrations of the two main acidifying air pollution components in 2005 – the actual scenario**

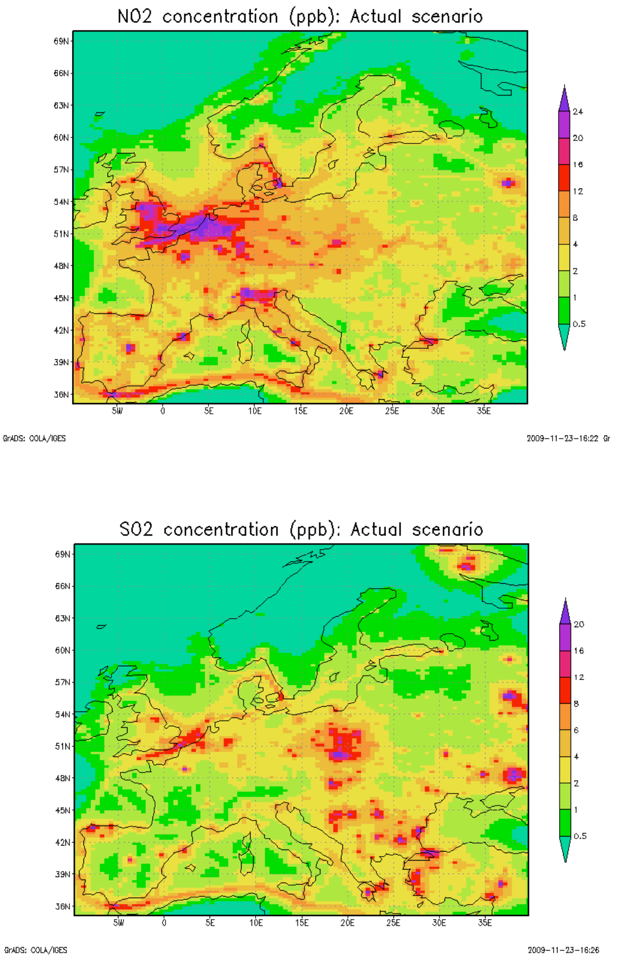


Figure 3.11 **Calculated annual mean ambient fine particulate matter concentrations in 2005 — the actual scenario**

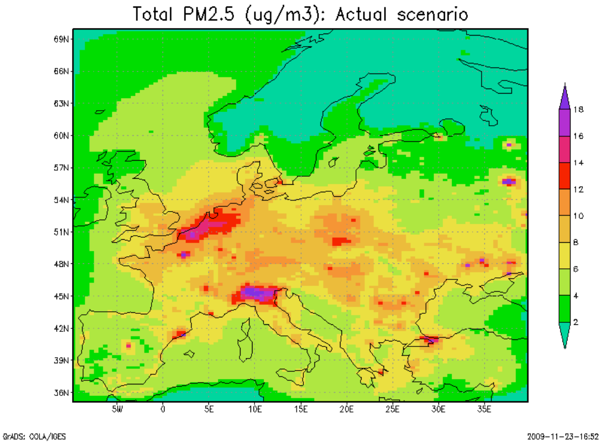
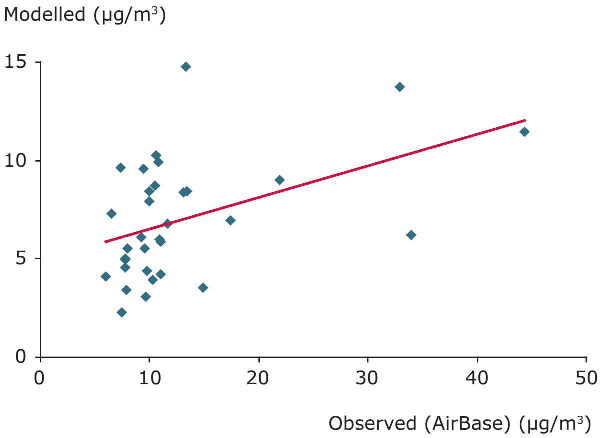


Figure 3.12 **Comparison of observed $PM_{2.5}$ rural background concentrations with modelled concentrations (this work)**



Source: AirBase, 2010.

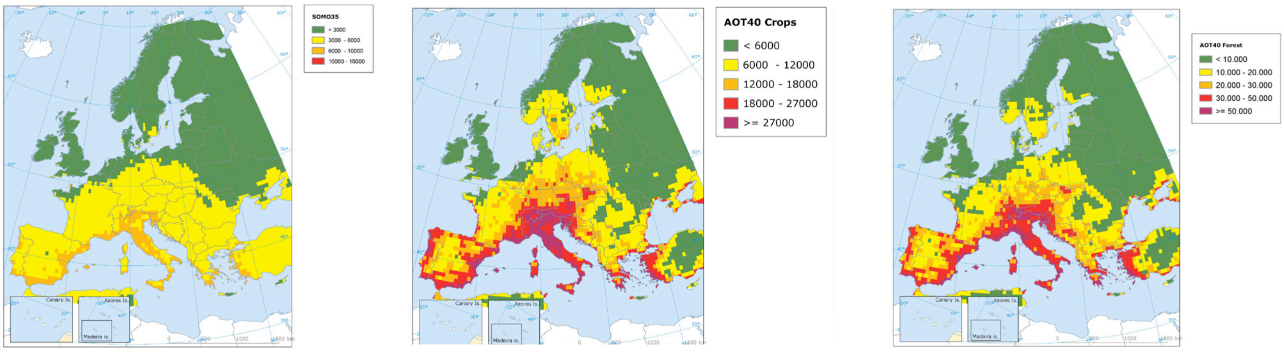
situation and an emission scenario, it is however expected that the bias arising from such uncertainties is largely cancelled out.

Ozone

Figure 3.13 shows the modelled ozone concentrations (expressed as the health parameter SOMO35 and the ecosystem parameters AOT40-crops and AOT40-forest) in Europe for the year 2005. Generally, as expected, the highest annual averaged concentrations of ozone occur in southern Europe. Over land, ozone tends to be lower in the atmosphere than above sea due to losses by dry deposition and quenching through reaction with NO. The heavily industrialised and densely populated areas in the Low Countries, the Ruhr area and England, where elevated levels of other air pollutants occur, show decreased levels of ozone.

Modelling of the health parameter SOMO35 shows a spatial distribution of concentrations similar to data collected from monitoring stations (Horálek *et al*. 2008), even though current model results underestimate the concentrations. The AOT40 parameters likewise show a good spatial correlation but, with exception of the Mediterranean coastal region, some underestimation of observed concentrations. This might cause an underestimation of ozone impacts on health and ecosystems. However, as argued above, this bias is expected to cancel out when comparing the environmental impacts for the modelled emission abatement scenarios.

Figure 3.13 Calculated annual mean ambient ozone concentrations in 2005. Left, SOMO35; middle, AOT40 for crops; right, AOT40 for forest – the actual scenario



3.3.2 *State: the effects of the selected abatement policies*

As shown above, European emission abatement policies for both road transport and industrial combustion have considerably reduced emissions of major air pollutants over the last 15 year (Figure 3.3). The present section reviews the ***changes*** in ambient concentrations resulting from these European emission abatement policies. All concentration maps shown are for the year 2005.

$PM_{2.5}$

Figure 3.14 shows the decrease in ambient fine particulate matter concentrations in Europe that has been achieved by introduction of the EURO standards in road transport and the introduction of BAT for large industrial combustion plants.

In Figure 3.15, the national average $PM_{2.5}$ concentrations for the *'actual'* scenario are compared with the *'no application'* scenarios for road transport and industrial combustion. As a result of introducing road transport standards, $PM_{2.5}$ concentrations show only a small decrease. In contrast, the reduction arising from implementation of BAT for large industrial combustion plants is larger – around 6 ppb in many countries.

SO_2

As is shown in Figure 3.16, introducing IPPC (BAT) in industrial combustion facilities has decreased SO_2 concentrations (the main acidifying component) in Europe between 0 and 100 ppb (depending on location) compared to the *'no application'* scenario. The largest reductions occurred mainly in the highly populated and industrialised belt from central England, across the Low Countries and

Figure 3.14 Effects of introducing road vehicle emissions standards (left) and IPPC in industrial combustion plants (right) on fine particulate matter concentrations in Europe in 2005

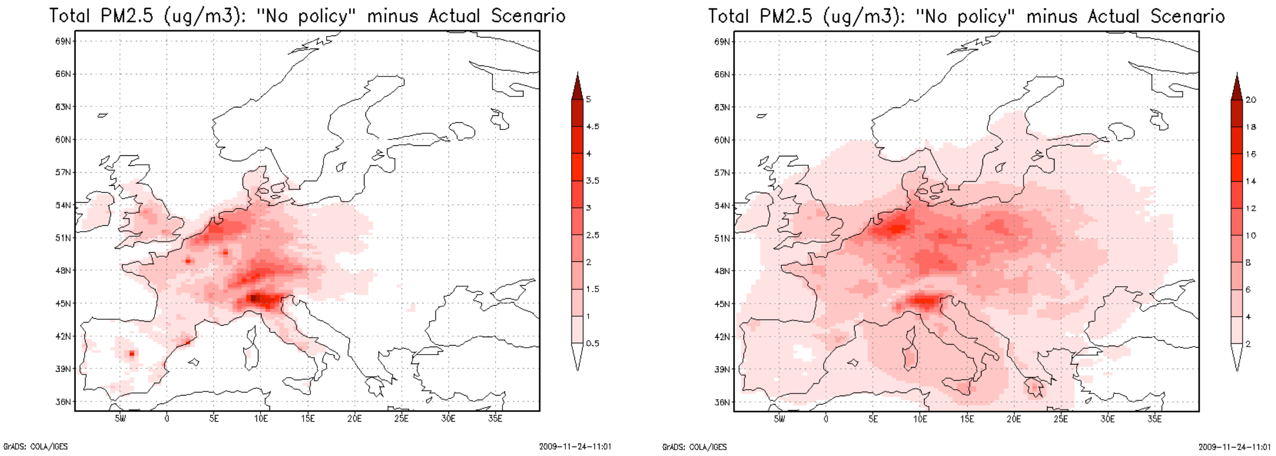


Figure 3.15 **Population weighted average $PM_{2.5}$ concentrations in 2005 for the actual situation, and for the *'no application'* scenarios for road transport and for industrial combustion plants**

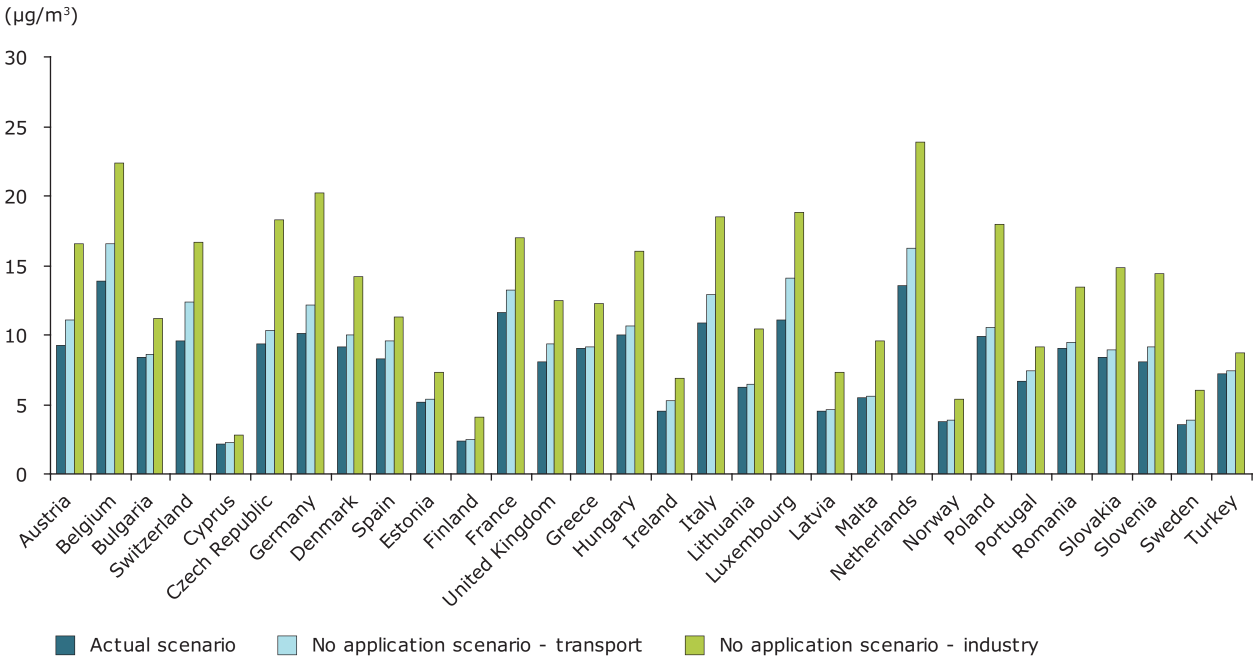
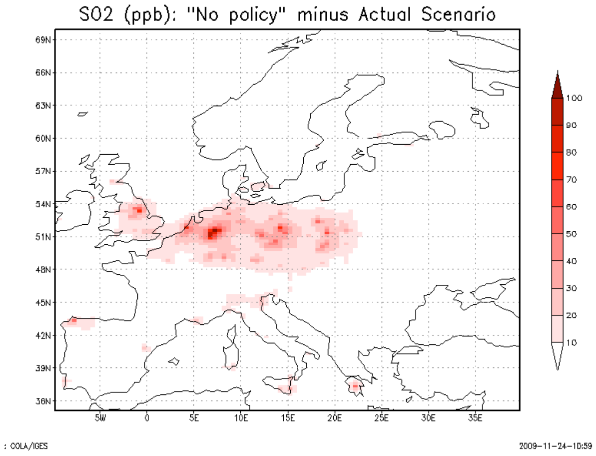


Figure 3.16 **Effects of introducing IPPC for industrial combustion plants on SO_2 concentrations in Europe in 2005**



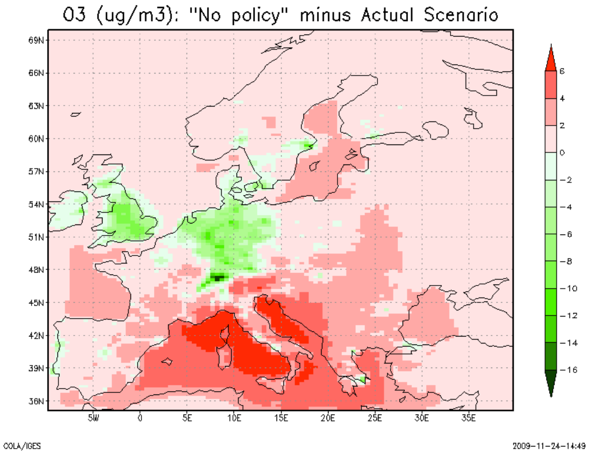
the Ruhr, towards southern Poland. Outside this industrialised belt in Europe, SO_2 reductions from the introduction of BAT are generally below 10 ppb.

Ozone

The effects of emission abatement measures on concentrations of ozone are more complicated (Figure 3.17). The green shades indicate an increase in ozone as a result of abatement measures, while red shades indicate a decrease. The reduced emissions from road transport resulting from the Euro standards has improved air quality in terms of tropospheric ozone in most of Europe. In a large area, including Benelux, England and Germany, however, ozone concentrations have increased as a result of the standards. Higher mean ozone concentrations are also apparent in monitoring data (Mol et al., 2009). The reason is the decrease in NO_X emissions, resulting in less chemical quenching of ozone.

The changes in ozone concentrations range from decreases of 4–6 μg/m³ (in the Balkans and Italy) to an increase of about 15 μg/m³ in southern Germany. Looking at Figure 3.17, it can be concluded that the regions with the highest ozone concentrations (southern Europe, the Mediterranean) benefit most from European road transport policies.

Figure 3.17 Effects of introducing Euro vehicle standards on annual mean tropospheric ozone concentrations in Europe in 2005



3.4 Impacts

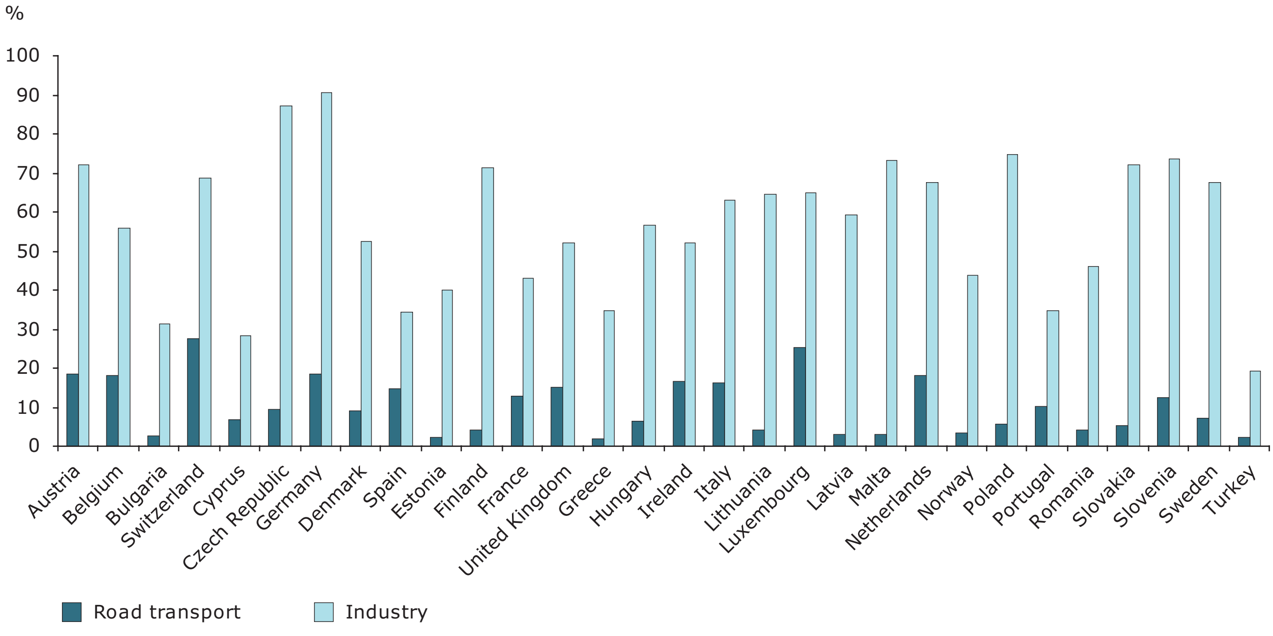
3.4.1 $PM_{2.5}$

The change in the number of years of life lost (YOLL) attributable to exposure to $PM_{2.5}$ for cardiopulmonary diseases and lung cancer has been estimated by comparing *'no application'* scenarios for the road transport and industrial combustion sectors with the *'actual'* (2005) scenario.

Averaged across all EEA member countries, abatement measures reduce the health impact of the road transport sector (in terms of YOLL) by some 13 % and of the industrial combustion sector by 60 %. For individual countries the difference in benefits varies strongly. For road transport, health impacts range from a 2.5 % decrease in YOLL in Bulgaria to more than 25 % in Luxembourg and Switzerland.

In the industrial combustion scenarios the benefits are much larger, in agreement with the larger reduction in $PM_{2.5}$ concentrations. Without abatement measures YOLL would be almost twice as high in some countries, such as the Czech Republic and Germany.

Figure 3.18 Percentage improvement in health benefits attributable to the reduced exposure of $PM_{2.5}$ (expressed as YOLL) relative to the '*no application*' scenario in 2005, arising as a result of introduction of the Euro standards for road transport and control of industrial combustion emissions



3.4.2 Ozone

Abatement measures in the road transport sector have reduced the impacts of ozone on human health and ecosystems (Figure 3.19). In contrast to the annual mean ozone concentrations (Figure 3.17) the higher ozone levels (expressed as SOMO35 or AOT40) are less sensitive to the chemical quenching by NO_X. With the exception of a few grid cells in the United Kingdom, the SOMO35 and AOT40 levels are currently lower than in the *'no application'* scenario. In all countries human exposure has been reduced due to road transport measures (Figure 3.20).

In the *'no application'* scenario for industrial combustion there is a strong reduction of the ozone precursor NO_X but not of the precursor NMVOC. Nitrogen oxides may play a double role in ozone formation. At large distances from sources a reduction in NO_X will result in lower ozone formation. Close to source, however, a reduction in NO_X may increase the ozone levels. For this reason, the *'no application'* scenario shows a mixed pattern, both increases and decreases in ozone are found compared to the *'actual'* scenario (Figure 3.20).

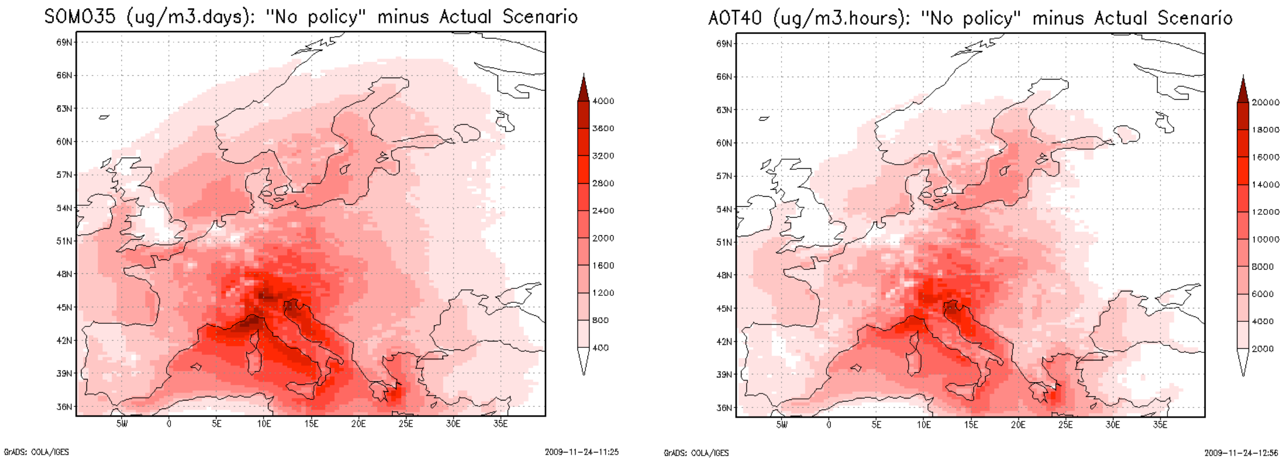
The ecosystem-related indicators AOT40-crops and AOT40-forest show similar trends. The 'no application' scenario for the road transport sector shows higher ozone levels all over Europe, whereas the 'no application' scenario for industrial combustion results in ozone values both higher and lower than in the 'actual 'scenario.

Impact on human health
In absolute numbers (YOLL, premature deaths), exposure to particulate matter is much more important than ozone exposure. The total impact of a scenario is therefore dominated by the changes in $PM_{2.5}$ exposure. Nevertheless, looking only at the health impacts of ozone, abatement measures in the road transport sector have resulted in a health benefit (in terms of reduced YOLL) of 5–25 %, with an average of 17 %.

The introduction of industrial combustion policies resulted in negative health impacts in nearly all EEA countries, with YOLL attributable to ozone exposure 17 % higher in the *'actual'* scenario than in the *'no application'* scenario. However, the total health impact ($PM_{2.5}$ and O_3) is positive.

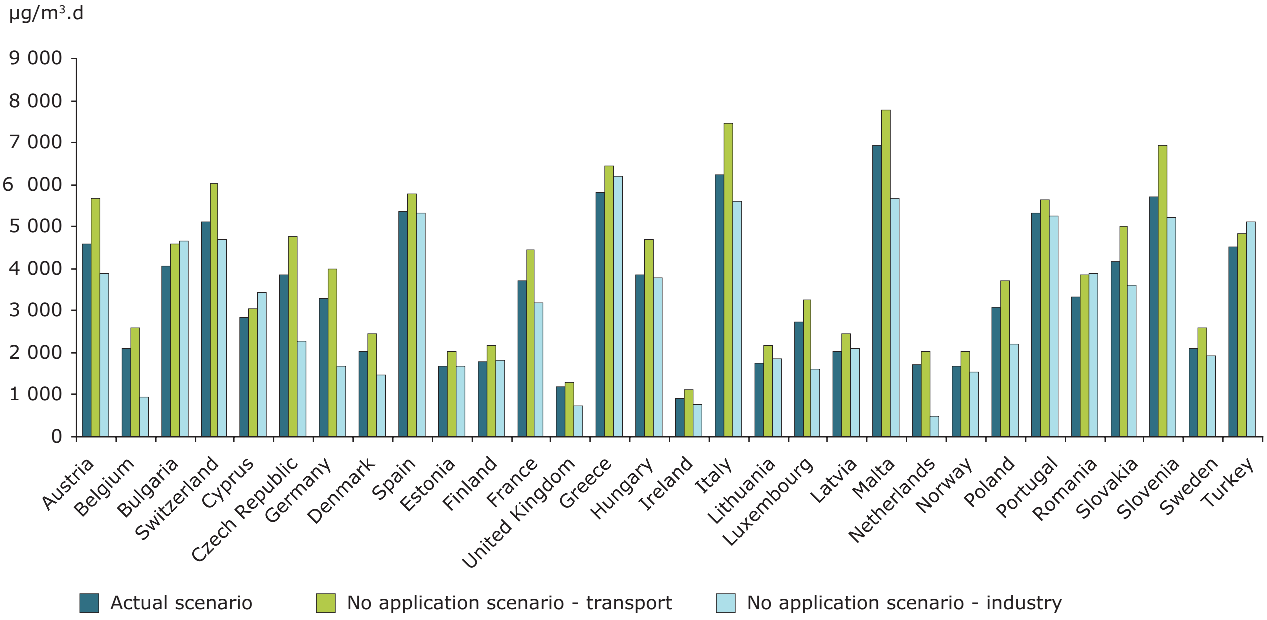
Impact on ecosystems
Results from the *'actual'* scenario indicate that 17 % of agricultural crops in EEA member countries are exposed to AOT40 above the target value and 75 % are exposed to levels above the long-term objective. The *'no application'* scenario for the road transport

Figure 3.19 Difference in ozone impact indicators for human health (SOMO35) and ecosystems (AOT40) in 2005 as a result of the introduction of the Euro standards in road transport


SOMO35 (ug/m3.days): "No policy" minus Actual Scenario

AOT40 (ug/m3.hours): "No policy" minus Actual Scenario

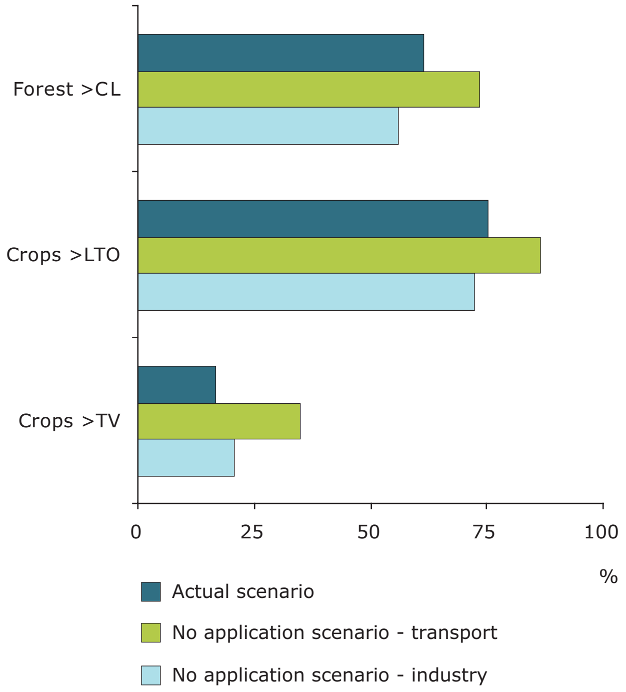
Figure 3.20 **Population-weighted average SOMO35 concentrations in 2005 for the '*actual*' scenario, and the '*no application*' scenarios in the road transport and industrial combustion sectors**



sector implies AOT40 exposure for crops as for forests that is higher than in the *'actual'* scenario.

The *'no application'* scenario in the industrial combustion sector delivers more complex results. Assuming no abatement measures, a larger fraction of forest and crops is exposed to levels above the critical level and long-term objective than in the *'actual'* scenario. However, a smaller area is exposed to levels above the target value (Figure 3.21).

Figure 3.21 **Percentage of forest area exposed to concentrations above the critical level, and percentage of the agricultural area exposed to AOT concentrations above target value and long-term objective**



4 Potential scope for further reductions

4.1 Emissions

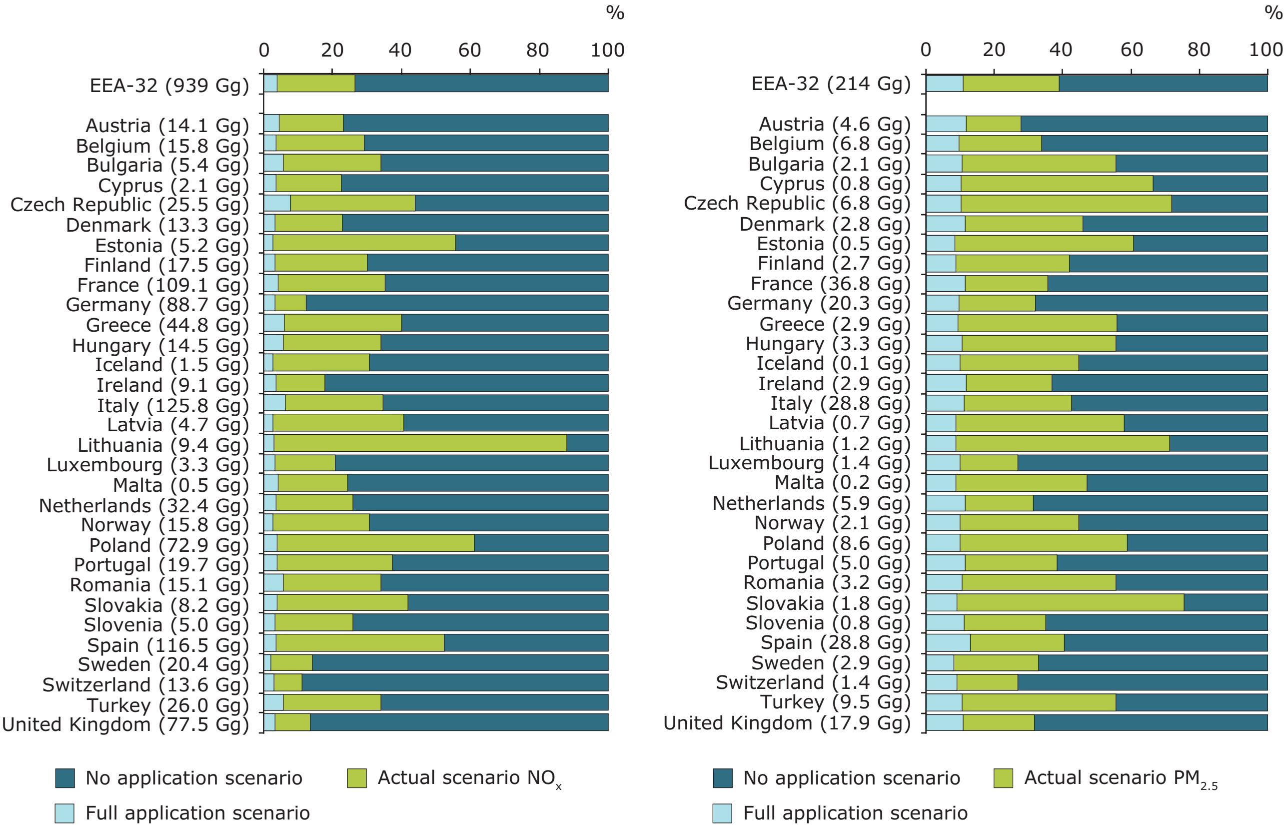
4.1.1 Road transport

The analysis in Subsection 3.1.2 above demonstrates that a theoretical full application of the latest Euro standards across the EEA would markedly reduce road transport emissions. The most important effects would be on NO_X emissions from gasoline-fuelled vehicles and $PM_{2.5}$ from diesel fuelled vehicles (Figure 3.6).

Figure 4.1 shows the achievements of EEA-32 countries in 2005 relative to unabated emissions, and the further emission reduction possible should all vehicles be equipped with Euro 4 technologies. It is evident that significant emission reductions can still be achieved.

Countries show clear differences with respect to the level of NO_X and $PM_{2.5}$ abatement from road transport. Four countries are significantly lagging behind the NO_X emission reductions in Europe as a whole: Estonia, Lithuania, Poland and Spain. Cyprus, the Czech Republic, Lithuania and the Slovak Republic appear slow in implementing the $PM_{2.5}$ emission reductions for diesel-fuelled vehicles. Obviously these countries would also show the largest improvements if all vehicles in the country were to apply Euro 4 technologies.

Figure 4.1 Potential relative emission reductions for the '*full application*' road transport scenario in 2005 compared with the '*actual*' and '*no application*' scenarios: NO_X from gasoline (left); and $PM_{2.5}$ from diesel (right)



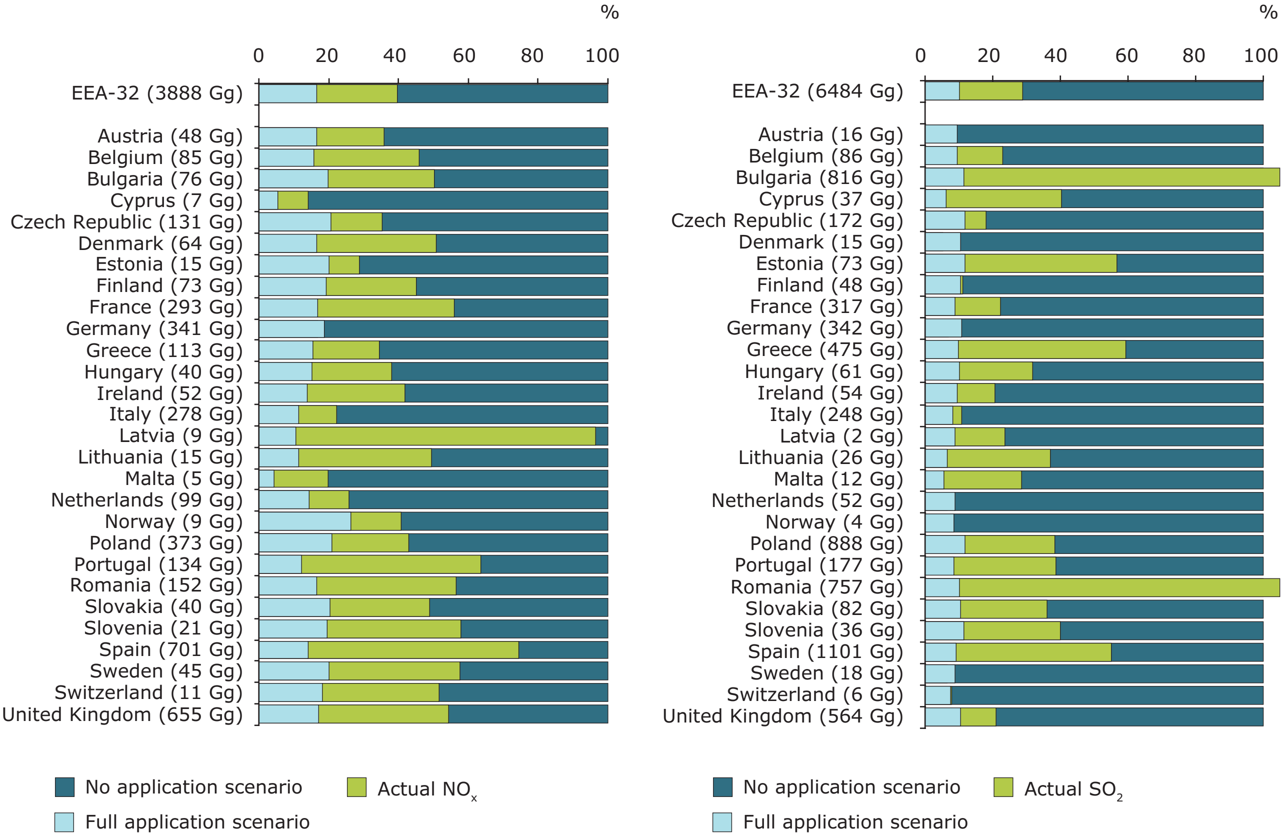
Note: The 'actual' scenario emission value for each country is indicated in brackets.

4.1.2 *Industrial combustion*

A similar analysis for the '*full application*' scenario for industrial combustion is provided in Figure 4.2. Some countries already appear to have reduced emissions to a greater extent than others. Austria, Denmark, Finland, Germany, Italy, Netherlands, Norway, Sweden and Switzerland in 2005 show emissions of SO_2 (almost) fully consistent with the BAT associated AELs in the LCP BREF. For NO_x only Germany seems to already have emissions consistent with the LCP BREF's AELs.

In Bulgaria and Romania, SO_2 emissions do not appear much abated at all, whereas Estonia, Greece and Spain could reduce SO_2 emissions by a factor of four or five for the '*full application*' scenario if all industrial combustion emissions were consistent with the BAT associated AELs of the LCP BREF. For NO_x the picture is less varied. While Latvia still has relatively high NO_x emissions from industrial combustion, in most other countries emissions could be halved if the emission levels of the LCP BREF AELS were attained.

Figure 4.2 Potential relative emission reductions for the '*full application*' industrial scenario in 2005 compared with the '*actual*' and '*no application*' scenarios: NO_x (left) and SO_2 (right)



Note: The 'actual' scenario emission value for each country is indicated in brackets.

4.2 Concentrations

4.2.1 *Fine particulate matter*

The theoretical '*full application*' road transport scenario would decrease fine particulate matter concentrations by a few tenths to 3 µg/m^3 across Europe. The largest improvement in air quality with respect to fine particulate matter would occur in the Po Valley. Improvements in more northern parts of Europe are smaller, presumably because the vehicle fleet is younger than in Mediterranean countries.

Larger decreases in $PM_{2.5}$ concentrations are calculated if all industrial combustion facilities achieve emissions consistent with the BAT associated AELs of the LCP BREF. Whereas in the road transport case the largest decreases in $PM_{2.5}$ concentrations are seen in more populated areas, in the industrial case the largest decreases are seen in Spain and the Balkans.

In countries where emissions already appear largely consistent with the BAT associated AELs (e.g. Germany, Denmark), no further improvement in air quality is anticipated under the '*full application*' scenario with respect to industrial combustion. In contrast, the theoretical '*full application*' scenario for road transport results in improvements in all countries. Improvements in countries outside the EEA region also occurs due to reduced transboundary transport of pollutants emitted in the EEA region.

Figure 4.3 Remaining potential improvements of fine particulate matter concentrations in Europe in 2005 following the '*full application*' scenario for road transport vehicles (left), industrial combustion (middle); and both policies fully applied (right)

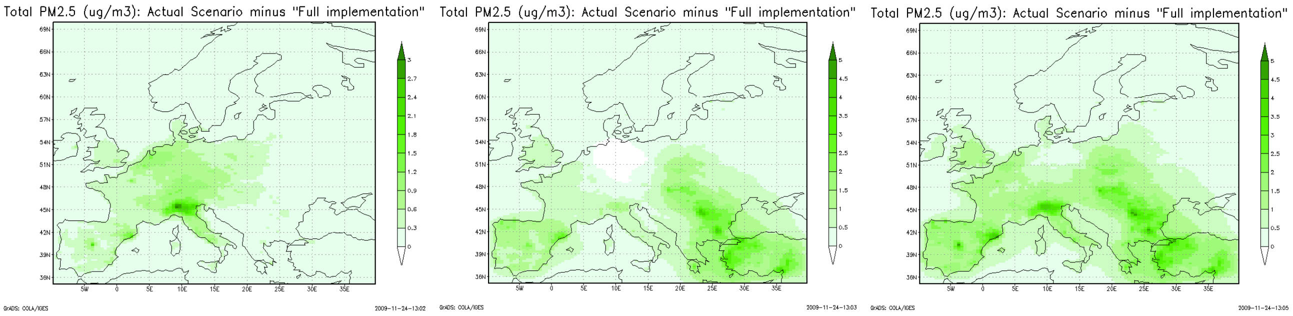


Figure 4.4 Population-weighted average $PM_{2.5}$ concentrations for the '*actual*' scenario, the '*full application*' scenario for road transport vehicles, the '*full application*' scenario for the industrial combustion sector, and the combined '*full application*' scenario for both sectors

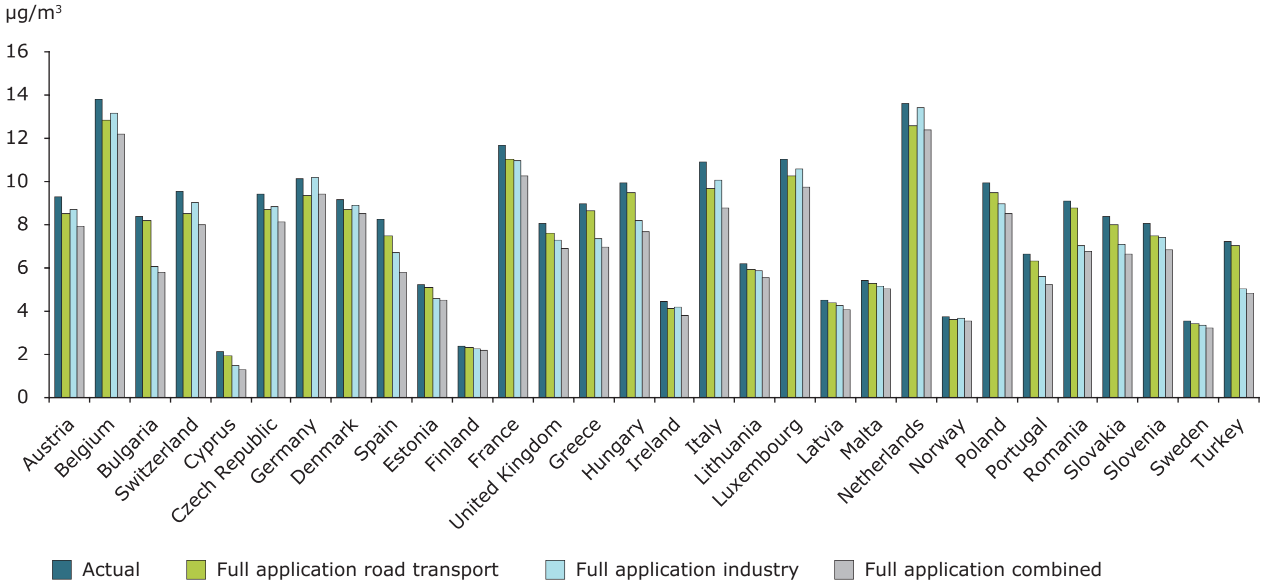
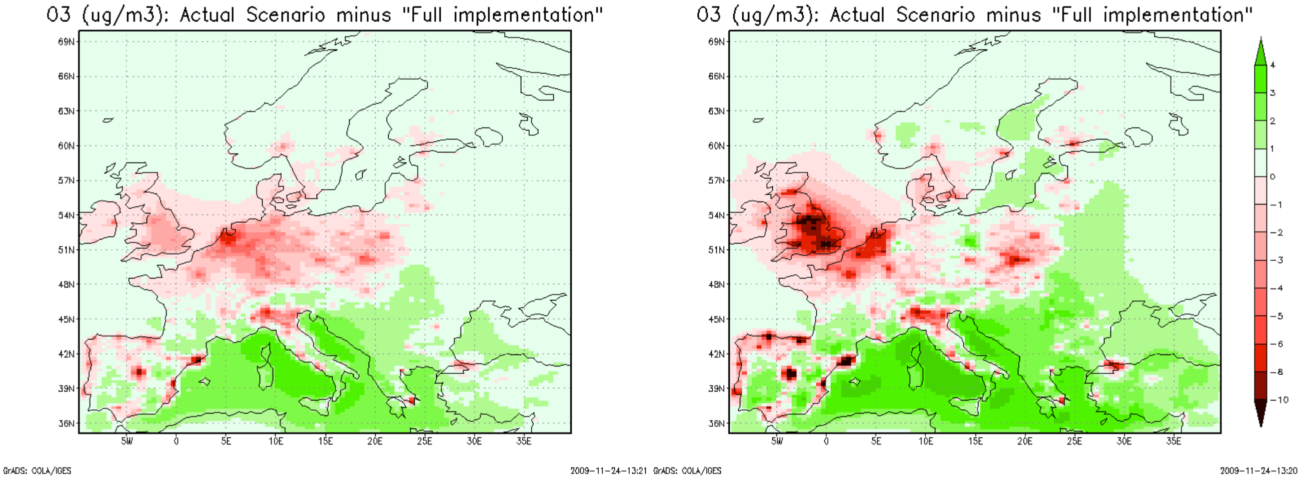


Figure 4.5 Remaining potential improvements of annual mean tropospheric ozone in Europe in 2005 for the road transport '*full application*' scenario (left) and with the '*full application*' of both road transport and industrial combustion policies (right)



4.2.2 *Tropospheric ozone*

The potential change in mean annual ozone concentrations in Europe that would occur if all vehicles in 2005 complied with Euro 4 standards is complicated. Ozone concentrations would go down in the Balkans and in some parts of southern France, Italy and the Iberian peninsula (Figure 4.5, left). In the rest of Europe, including the major populated areas (larger cities and towns, Po valley) annual ozone concentrations would actually increase by a few µg/m^3.

Combined implementation of Euro 4 standards and BAT associated AELs results in greater increases in ozone in north-western Europe (Benelux and the United Kingdom).

4.3 Environmental impacts

4.3.1 *Health*

Figure 4.6 shows possible health benefits of reduced $PM_{2.5}$ concentrations arising from full application of abatement measures in the road transport sector, the industrial combustion sector and both sectors. Benefits resulting from a full compliance with BAT associated AELs are on average twice as substantial those arising from full application of Euro standards. Non-linearities play a minor role in the estimates: when the benefits of the two sectoral scenarios are added, their sum is almost equal to the benefits in the combined scenario.

The impact of policy measures on ozone gives, again, a more complex picture. Figure 4.7 shows the impact on ozone arising from the combined '*full application*' scenarios for the road transport and industrial combustion sectors. This would result in an increase in SOMO35 values (i.e., negative health impacts) and AOT40 in the north-western Europe (Belgium, the Netherlands and the United Kingdom).

The combined '*full application*' scenarios for the road transport and industrial combustion sectors would also produce negative health impacts in the Belgium, the Netherlands and the United Kingdom (Figure 4.8). For other EEA-32 countries, the benefits resulting from the '*full application*' scenario for the road transport sector is on average twice as high as the benefits from the '*full application*' scenario for industrial combustion.

For the EEA region, full application of abatement measures in both sectors confers a 10 % reduction in YOLL due to lower ozone levels. Note that as the health impacts attributable to $PM_{2.5}$ exposure are much larger than those attributable to ozone exposure, the health losses when both pollutants are considered are also reduced for the BeNeLux and southern England regions.

Figure 4.6 Percentage improvement in health benefits attributable to the reduced exposure of $PM_{2.5}$ (expressed as YOLL) relative to the '*actual*' scenario in 2005, for the road transport and industry '*full application*' scenarios, and the two '*full application*' scenarios combined

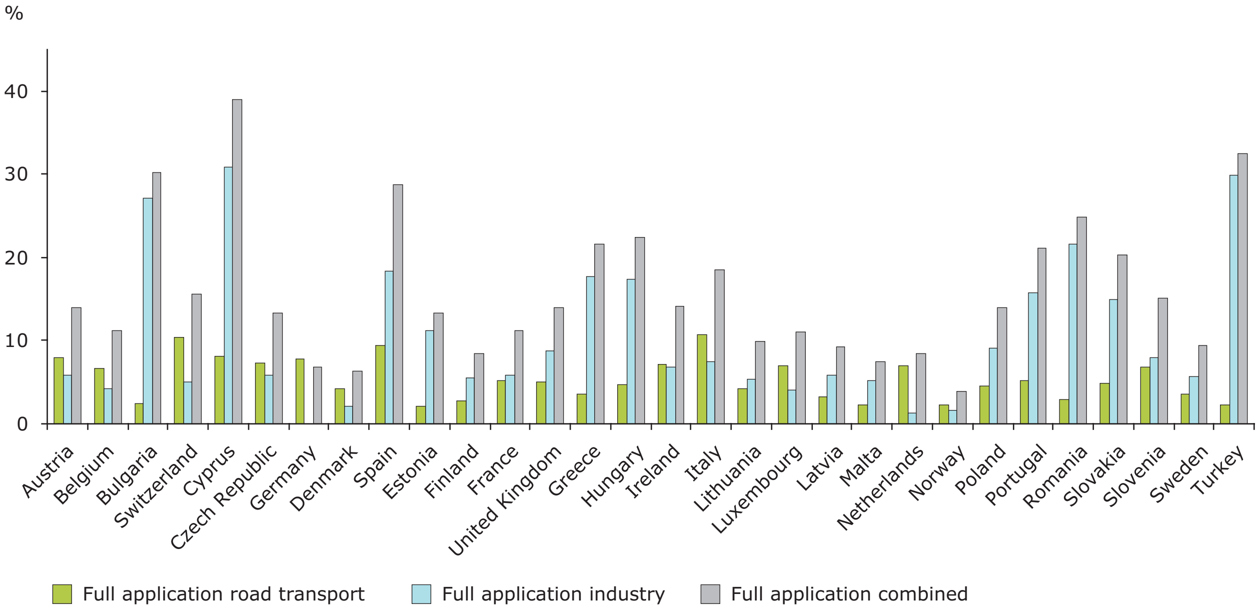


Figure 4.7 Ozone impact indicators for ecosystems (AOT40) and human health (SOMO35) in 2005 with combined '*full application*' scenarios for the road transport and industrial combustion sectors

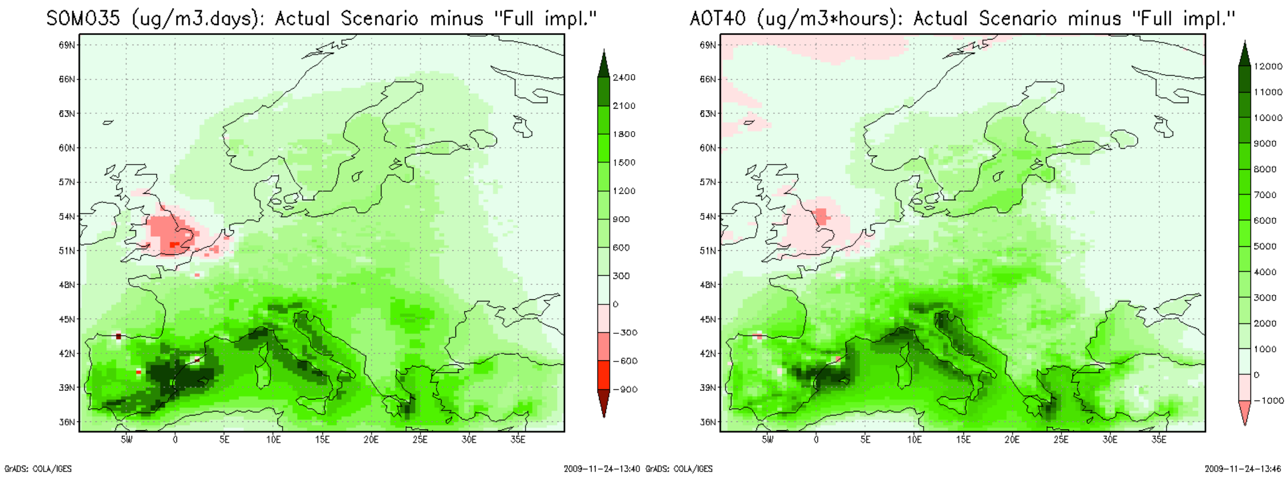
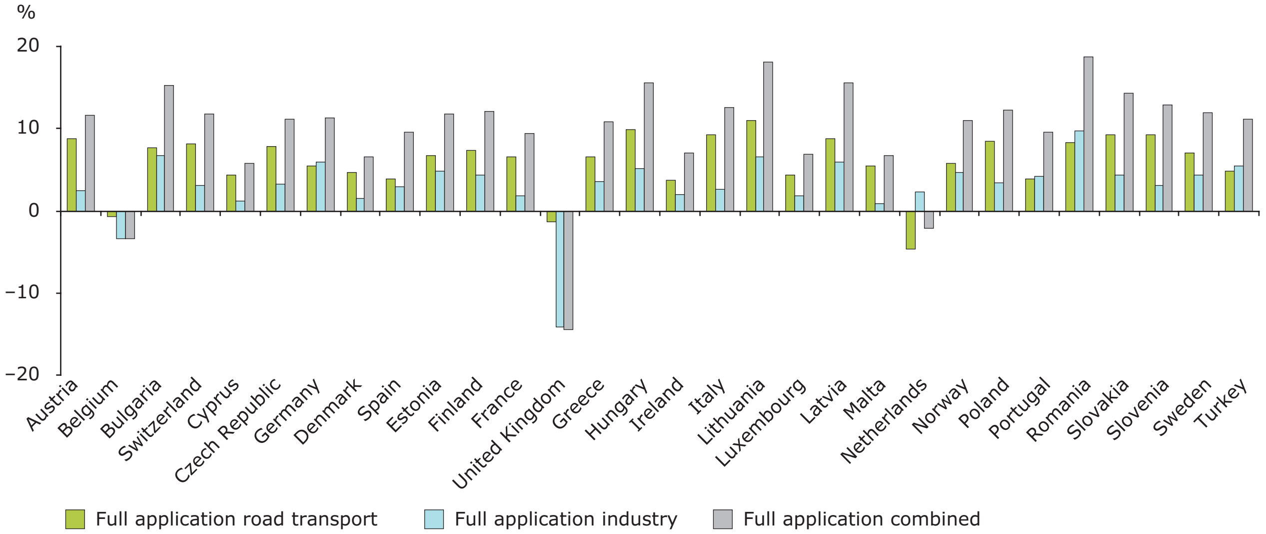


Figure 4.8 Percentage improvement in health benefits attributable to the reduced exposure of ozone (expressed as YOLL) relative to the 'actual' scenario in 2005, for the road transport and industry *'full application'* scenarios, and the two *'full application'* scenarios combined

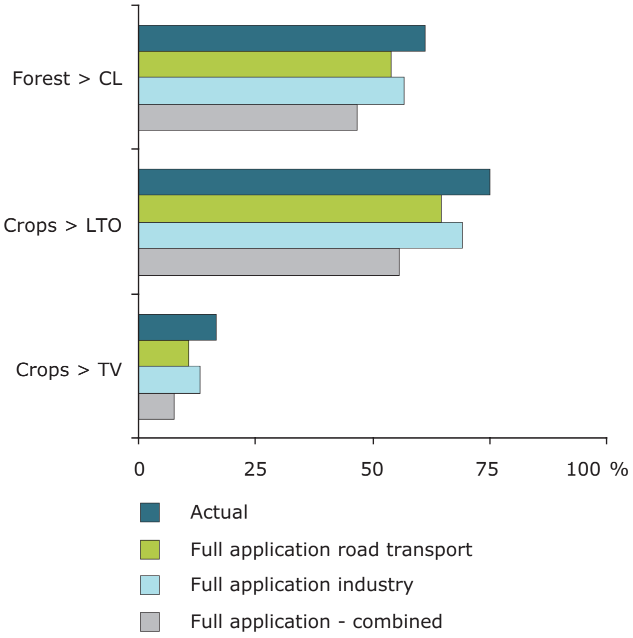


Note: Negative values correspond to a reduction in health benefits.

4.3.2 *Ecosystems*

The ozone exposure of crops and forest will be reduced for the '*full application*' scenarios for road transport or industrial combustion, or full application of both policies (Figure 4.9). As Figure 4.7 shows, full application of Euro standards may lead to a small increase in AOT40 in the Netherlands and southern United Kingdom. As this increase is mostly in the urban areas, the impact on crops and vegetations is relatively small. However, even in the event of full application of abatement measures in both sectors, more than 45 % of Europe's forests are exposed to ozone concentrations above the critical level. The model reveals significant differences across Europe, with no exceedances of the critical level in Ireland, the Nordic countries and the United Kingdom, compared to exceedances for 100 % of the forest area in more southern countries (for example, Austria, Italy, Slovenia and Switzerland).

Figure 4.9 Percentage of agricultural area exposed to ozone concentrations above target value (TV) and long-term objective (LTO) and percentage of forest area exposed to concentrations above the critical level (CL) for the '*actual*' scenario', the '*full application*' scenario for the road transport and industrial combustion sectors, and the combined '*full application*' scenarios



5 Conclusions

Within the DPSIR chain, policy responses to avoid unwanted health and other effects of air pollution are often directed towards addressing the drivers and the pressures behind emissions. Once air pollutants have entered the atmosphere, policymakers clearly do not have many options to control the subsequent exposure that may occur.

This study assesses the effectiveness of two sets of policy instruments. These policies aim to reduce emissions from two major sources that cause significant air pollution problems: acidifying air pollutants that damage ecosystems, soils and cultural heritage; and fine particulate matter and ambient ozone which both harm human health and for ozone, also vegetation.

Abating air emissions from road transport

Particulate matter

Emissions of primary particulate matter from road transport decreased by around 14 % between 1990 and 2005 (Figure 3.5), mainly due to improvements in diesel-fuelled vehicles. Without the introduction of the Euro standards for road transport vehicles, emissions would have been more than doubled during this period.

The situation with respect to particulate matter precursors is more complicated (Figure 3.6). Emissions of CO and NMVOC from road transport are almost completely caused by gasoline-fuelled vehicles. The introduction of Euro standards has reduced such emissions considerably over time. In contrast, emissions of NO_X are due to both gasoline- and diesel-fuelled vehicles. The introduction of the Euro standards has not produced as large decreases of particulate matter emissions as abatement measures for the industrial combustion plants have done.

Ambient concentrations of fine particulate matter have decreased, especially in the heavily polluted areas of the Po Valley and the countries surrounding the southern part of the North Sea. A '*full application*' scenario involving the theoretical implementation of Euro 4 standards for all road vehicles, shows that further decreases would occur, particularly in the Po Valley.

For fine particulate matter from the road transport sector (tail pipe emissions only), NO_X makes the predominant contribution of the individual pollutants, which in a series of photochemical processes is converted into nitrate secondary particulate matter. This observation should be interpreted with care. Highest concentrations of road-transport-related fine particulate matter are obviously at the kerbside of the road. At these locations, the travel time of air pollutants from the passing tailpipes is too short to convert NO_X to particulate matter aerosols prior to exposure. Fine particulate matter concentrations at the kerbside therefore are a sum of the direct PM emissions of passing vehicles and secondary particulate matter that originates from NO_X and other precursor emissions farther away. The latter will more generally be part of the urban background, rather than being directly caused by the traffic on the immediate nearby road.

It is expected that a further decrease of NO_X emissions from road vehicles would further decrease ambient particulate matter aerosol concentrations considerably. Part of this would be achieved if all vehicles were to comply with the Euro 4 standards (Figure 4.3). Further decreases can only be achieved by decreasing the NO_X emissions from diesel-fuelled vehicles (Figure 3.4). This would most probably decrease the background of fine particulate matter considerably.

The numbers of years of life lost (YOLL) attributable to $PM_{2.5}$ has fallen by 2–25 % in EEA countries following the introduction of the road transport policies. A further improvement of up to 10 % on average is predicted under the road transport '*full application*' scenario.

Ozone

This study shows that the introduction of the Euro standards has resulted in a significant decrease in emissions of ozone precursors. The effects of decreasing emissions of ozone precursors on ambient concentrations of ozone are complex. In some areas of Europe, concentrations are increasing while emissions are decreasing. This is the consequence of the complicated non-linear processes involved in ozone photochemistry in the atmosphere.

Both the SOMO35 and AOT40 indicators show that abatement measures have diminished adverse health impacts. The greatest reductions are found in the Mediterranean area and particularly in the Po Valley. The result of the road transport policies is a 5–25 % reduction in YOLL. For ecosystems, the road transport policies resulted in a decrease in exposure to AOT40 above the target value, both for crops and forests.

Full application of the Euro 4 standards would result in a 10 % health benefit (in terms of reduced YOLL) due to lower ozone levels. For ecosystems, the ozone exposure of crops and forests will decrease but because the impact of these policies is greatest in urban areas, the potential for further reduction in exposure is relatively small.

Abating air emissions from large industrial combustion plants

The introduction of abatement measures in industrial combustion plants has significantly improved air quality in Europe in terms of both acidifying pollutants and fine particulate matter. Concentrations of both pollutants in ambient air would be around twice as high if these abatement measures had not been implemented. The major improvements occurred in the heavily populated and industrialised regions of Europe.

The '*full application*' scenario for industrial combustion plants shows that further improvements of air quality, particularly in the Balkans and Turkey, would be possible. In large parts of north-western Europe, such large improvements are no longer expected.

Abatement of $PM_{2.5}$ emissions from industrial combustion reduces YOLL by of 30–90 %, which is far more than similar measures targeting the road transport sector.

Policies addressing industrial combustion plants have achieved a strong reduction of NO_X concentrations but not of ozone. This is because the complex atmospheric chemistry in the formation of tropospheric ozone means that substantial reductions of NO_X may actually lead to increased concentrations of ozone, as is observed in some areas. In these cases, the policies mean that crops and forests are more exposed to ozone, as reflected in increased SOMO35 and AOT40 values.

Under the '*full application*' scenario for industrial combustion plants, a further reduction in YOLL due to $PM_{2.5}$ exposure of between 5 % and 30 % in individual EEA countries could occur. A small reduction in YOLL due to ozone exposure is predicted and, similarly, a small decrease in forests and crops exposed to ozone.

Abating air emissions from both road transport and large industrial combustion plants

Chapter 4 presented an assessment of how air quality would alter if the '*full application'* scenarios for the road transport and industrial combustion sectors were combined i.e. a theoretical scenario under which all road transport vehicles would be Euro 4 compliant, and emissions from industrial facilities would be consistent with the BAT associated AELs of the LCP BREF.

Concentrations of fine particulate matter in ambient air would be significantly lower, especially in industrialised areas and cities. Health benefits related to $PM_{2.5}$ from fully implementing both policies are similar to the aggregate health benefits from full implementation of the two individual policies and are positive in all countries.

In contrast, fully implementing policies in the two sectors would increase ozone concentrations in certain populated areas. This is due to the complicated non-linear chemical processes concerning ozone formation in the atmosphere. Reducing NO_X emissions also diminishes the possibilities for ozone reductions. So while SOMO35 and AOT40 values would decrease in most of Europe, an increase would be seen over Belgium, the Netherlands and southern United Kingdom. Therefore, the reduction in YOLL arising from full implementation of both policies is around 10 % for most countries and for Europe as a whole but is negative for Belgium, the Netherlands and the United Kingdom.

Recommendations

This study shows that air quality, as expressed in terms of acidifying pollutants and fine particulate matter, has improved considerably by European emission abatement policies for road transport and industrial combustion installations. These policy instruments have thus have been very successful in this respect.

Not all possible improvements have yet been achieved, however. Especially in the Balkans and central and southern Europe, further significant improvements are expected should older vehicles be removed from the roads and be replaced by newer less polluting vehicles (e.g. Euro 4), and industrial combustion facilities lowered emissions to levels consistent with the BAT associated AELs.

Road transport emission reduction measures have especially reduced NO_X, CO and NMVOC emissions from gasoline-fuelled vehicles and $PM_{2.5}$ emissions from diesel-fuelled vehicles. CO and (exhaust) NMVOC cannot be reduced much further. NO_X emissions from diesel-fuelled vehicles have so far not been considerably reduced. To further reduce road transport's impact on air quality, diesel NO_X emissions could for example be targeted. Specific NO_X abatement technologies for diesel-powered vehicles such as selective catalytic reduction (SCR) (especially for heavy-duty vehicles) are one possible option.

This study has only considered tail pipe emissions of $PM_{2.5}$. Fine particulate matter is also emitted from brake and tyre wear, independent of the amount fuel used. If $PM_{2.5}$ emissions from diesel-fuelled vehicles are further reduced by new more strict emission standards, the non-exhaust emissions from the whole vehicle fleet will become proportionally more important.

The situation for ozone is somewhat different. Although the emissions of all ozone precursors have been reduced, ambient concentrations of ozone do not show a corresponding decrease. Further emission reductions of the precursor emissions are possible under the '*full application*' scenarios for road transport and industrial combustion. However, due to the chemical non-linearities involved in ozone formation chemistry, this is actually likely to increase the ozone in certain populated areas of Europe. To decrease ozone concentrations, other sources of ozone precursors also need to be considered, such as NMVOC emissions from solvent use.

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Annex 1 TNO Emission Assessment Model (TEAM)

The algorithm

In this study, emissions were calculated using the TNO Emission Assessment Model (TEAM) (Pulles et al., 2006; Pulles et al., 2007). The model allows for explicit modelling of economic, technological and behavioural elements. Data on ***activity rates*** represent the productivity of a sector within an economy or society.
A table of ***technologies*** defines all technologies available to perform these activities. A selection table allows one or more technologies to be identified for each activity. This table models the ***penetration*** of available technologies into the economy and the society.

The emissions are calculated from these tables using the following algorithm:

$$E_{pollutant}(t) = \sum_{activities}\left(\sum_{technologies}\left(AR_{activity}(t)\times P_{activity,technology}(t)\times EF_{technology,\,pollutant}\right)\right)$$

$$\text{for all } activities, \text{ for all } t: \sum_{technologies} P_{activity,technology}(t) = 100\%$$

Therefore, the three relevant dimensions ('economy', 'technology' and 'behaviour') of emissions are explicitly modelled in this approach and the contributions of either of the three can be studied explicitly. This algorithm is implemented in the database.

with

$E_{pollutan}t(t)$	The emission of a *pollutant* at a time interval *t*
$AR_{activity}(t)$	The activity rate for a certain *activity* at time interval *t*
$P_{activity,technology}(t)$	The penetration: the fraction (at time interval *t*) of the *activity* performed using a specific *technology*
$EF_{technology,\,pollutant}$	The emission factor, determining the linear relation between the activity rate and the resulting emission of a certain *pollutant*, using a specific *technology*

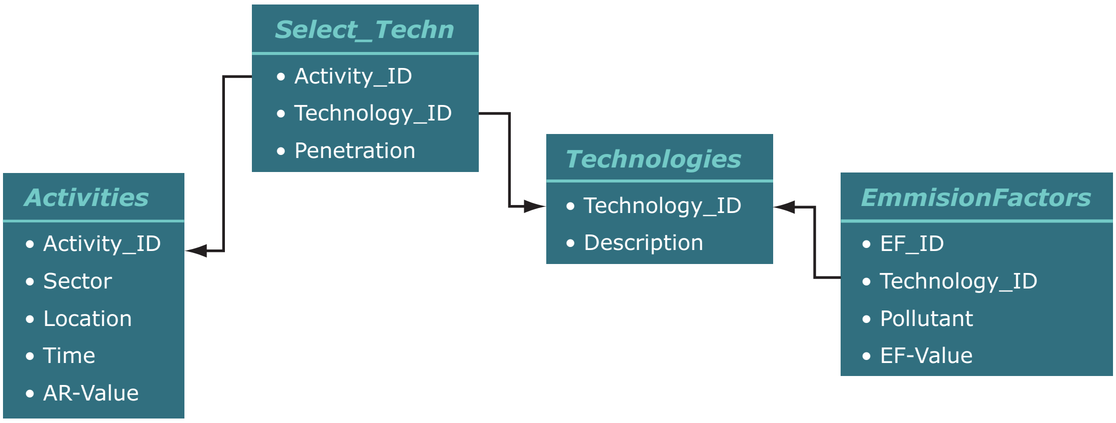
TEAM database structure

The algorithm above is applied for any location that is included in the inventory. Since the summations in these calculations might include a long list of activities, the most suited tool for creating emissions inventories is a database. In accordance with the algorithm, three main data tables are included in this database:

- a table of activity rates providing information on the intensity of each activity or sector at every relevant location and at every relevant time period;
- a table of emission factors, linked to a table of all available technologies;
- a table selecting one or more technologies for each activity in the database.

Figure A.1.1 presents a schematic overview of the relations between these core tables in a generalised database structure. The relations between the tables are indicated by the arrows.

Figure A.1.1 Schematic overview of the relationship between the core tables within the TNO Emission Assessment Model (TEAM)



Within TEAM, emissions are calculated from these tables using the following algorithm:

$$E_{pollutant,scenario}(t) = \sum_{activities} \left(\sum_{technologies} \left(AR_{activity}(t) \times P_{activity,technology}(t) \times EF_{technology,pollutant} \right) \right),$$

where, for all *activities* and all *t*: = 100 %, $\sum_{technologies} P_{activity,technology}(t)$

where:

$E_{pollutant}(t)$	The emission of a *pollutant* at a time interval *t*
$AR_{activity}(t)$	The activity rate for a certain *activity* at time interval *t*
$P_{activity,technology}(t)$	The penetration: the fraction (at time interval *t*) of the *activity* performed using a specific *technology*
$EF_{technology,\ pollutant}$	The emission factor, determining the linear relation between the activity rate and the resulting emission of a certain *pollutant*, using a specific *technology*

TEAM scenarios

For the purpose of this study, the model was slightly enhanced to allow different scenarios to be analysed within the database. In this respect, two types of scenarios were considered:

- 'Activity scenarios' are scenarios in which the activity rate was varied. For instance, in addition to the actual activity scenario, two other scenarios were also considered in which the growth in activity was assumed to be identical to the growth in the population or the economy (GDP). In the database this was implemented by adding an extra field 'Scenario_ID' to the 'AR' table. The AR value then not only depended on the Sector, Location and Time, but also on a specific AR-Scenario.
- Technology scenarios are scenarios in which the same activity data are used for various scenarios but the technologies applied to those activity data are varied. For instance, it was assumed that for a certain activity the oldest ('conventional') technologies were fully applicable in the entire vehicle fleet, or that the most sophisticated control systems were applicable to the entire vehicle fleet. In the database this was implemented by adding an extra field 'Scenario_ID' to the 'Select_Technology' table, adding an extra dimension to this table. This allowed for the selection of multiple technology splits for each activity rate (Activity_ID) for each technology scenario.

Annex 2 Vehicle types, classes and technologies with emission factors as used in this study

Data source

The vehicle technologies considered in this study are listed in the present annex and were sourced from COPERT 4 and TREMOVE (University of Thessaloniki, 2010; TREMOVE, 2010). Each of the technologies considered in this study has a set of associated emission factors, one for each relevant pollutant. The emission factors were sourced from the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2009), which provides emission factors identical to those used in COPERT 4.

Passenger cars

Emission factor					**Pollutant**			
					CO	NMVOC	NO_X	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
Passenger Cars	Diesel	Euro 1	Diesel < 2,0 l	PC Euro 1 – 91/441/EEC	192	21,8	295	37,5
			Diesel > 2,0 l	PC Euro 1 – 91/441/EEC	142	24,4	219	27,8
		Euro 2	Diesel < 2,0 l	PC Euro 2 – 94/12/EEC	136	14,7	297	24,3
			Diesel > 2,0 l	PC Euro 2 – 94/12/EEC	106	34,9	230	18,8
		Euro 3	Diesel < 2,0 l	PC Euro 3 – 98/69/EC Stage2000	42,1	8,68	338	17,9
			Diesel > 2,0 l	PC Euro 3 – 98/69/EC Stage2000	30,7	6,02	247	13,1
		Euro 4	Diesel < 2,0 l	PC Euro 4 – 98/69/EC Stage2005	42,1	6,94	261	14,8
			Diesel > 2,0 l	PC Euro 4 – 98/69/EC Stage2005	30,7	5,07	190	0
		Unabated	Diesel < 2,0 l	Conventional	264	60,1	208	91,2
			Diesel > 2,0 l	Conventional	264	60,1	330	91,2
	Gasoline	ECE 15	Gasoline < 1,4 l	ECE 15/02	8 000	1 030	723	0,843
				ECE 15/03	8 140	1 030	783	0,843
				ECE 15/04	5 380	992	799	0,949
			Gasoline > 2,0 l	ECE 15/02	5 520	799	635	0,581
				ECE 15/03	5 620	799	833	0,581
				ECE 15/04	3 670	933	744	0,638
			Gasoline 1,4–2,0 l	ECE 15/02	6 830	924	698	0,719
				ECE 15/03	6 950	923	728	0,719
				ECE 15/04	4 630	892	865	0,805
		Euro 1	Gasoline < 1,4 l	PC Euro 1 – 91/441/EEC	1 730	231	181	0,983
			Gasoline > 2,0 l	PC Euro 1 – 91/441/EEC	892	139	112	0,643
			Gasoline 1,4–2,0 l	PC Euro 1 – 91/441/EEC	1 350	222	152	0,825
		Euro 2	Gasoline < 1,4 l	PC Euro 2 – 94/12/EEC	988	124	100	0,992
			Gasoline > 2,0 l	PC Euro 2 – 94/12/EEC	447	70,1	58	0,616
			Gasoline 1,4–2,0 l	PC Euro 2 – 94/12/EEC	764	122	85,2	0,841
		Euro 3	Gasoline < 1,4 l	PC Euro 3 – 98/69/EC Stage2000	864	68,2	39,6	0,444
			Gasoline > 2,0 l	PC Euro 3 – 98/69/EC Stage2000	450	44,7	25,9	0,313
			Gasoline 1,4–2,0 l	PC Euro 3 – 98/69/EC Stage2000	661	65,1	33,1	0,371
		Euro 4	2-Stroke	Conventional	3 630	2770	178	0
			Gasoline < 1,4 l	PC Euro 4 – 98/69/EC Stage2005	274	47,5	23,9	0,424
			Gasoline > 2,0 l	PC Euro 4 – 98/69/EC Stage2005	132	28	14	0,265
			Gasoline 1,4–2,0 l	PC Euro 4 – 98/69/EC Stage2005	217	44,8	20,4	0,362
			Hybrid Gasoline < 1,4 l	PC Euro 4 – 98/69/EC Stage2005	0,865	18,2	7,78	0
			Hybrid Gasoline > 2,0 l	PC Euro 4 – 98/69/EC Stage2005	0,865	18,2	7,78	0
			Hybrid Gasoline 1,4–2,0 l	PC Euro 4 – 98/69/EC Stage2005	0,865	18,2	7,78	0

Passenger cars (cont.)

Emission factor					Pollutant			
					CO	NMVOC	NO_X	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
		Unabated	2-Stroke	Conventional	3 630	2 770	178	0
			Gasoline < 1,4 l	ECE 15/00-01	10 300	1 030	638	0,81
				Improved Conventional	5 380	992	799	0,949
				Open Loop	4 390	819	550	0,885
				PRE ECE	11 300	1 050	546	0,693
			Gasoline > 2,0 l	ECE 15/00-01	7 790	871	945	0,613
				PRE ECE	7 760	794	733	0,475
			Gasoline 1,4–2,0 l	ECE 15/00-01	8 730	913	707	0,687
				Improved Conventional	4 630	892	865	0,805
				Open Loop	2 040	529	385	0,734
				PRE ECE	9 400	912	593	0,576
	LPG	Euro 1	LPG	PC Euro 1 – 91/441/EEC	1 400	285	164	0
		Euro 2	LPG	PC Euro 2 – 94/12/EEC	979	136	73,6	0
		Euro 3	LPG	PC Euro 3 – 98/69/EC Stage2000	821	76,1	42,5	0
		Euro 4	LPG	PC Euro 4 – 98/69/EC Stage2005	384	37	23,3	0
		Unabated	LPG	Conventional	2 440	397	833	0

Light duty vehicles

Emission factor					Pollutant			
					CO	NMVOC	NO_X	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
Light Duty Vehicles	Diesel	Euro 1	Diesel < 3,5 t	LD Euro 1 – 93/59/EEC	168	40,9	354	34
		Euro 2	Diesel < 3,5 t	LD Euro 2 – 96/69/EEC	168	43,3	354	34
		Euro 3	Diesel < 3,5 t	LD Euro 3 – 98/69/EC Stage2000	137	27,3	299	22,7
		Euro 4	Diesel < 3,5 t	LD Euro 4 – 98/69/EC Stage2005	109	10,2	241	11,9
		Unabated	Diesel < 3,5 t	Conventional	349	34,6	432	92,6
	Gasoline	Euro 1	Gasoline < 3,5t	LD Euro 1 – 93/59/EEC	1 990	138	127	0,518
		Euro 2	Gasoline < 3,5t	LD Euro 2 – 96/69/EEC	1 330	68,5	51,8	0,518
		Euro 3	Gasoline < 3,5t	LD Euro 3 – 98/69/EC Stage2000	1 140	42,6	29,1	0,248
		Euro 4	Gasoline < 3,5t	LD Euro 4 – 98/69/EC Stage2005	453	28,8	14,4	0,248
		Unabated	Gasoline < 3,5t	Conventional	6 740	909	817	0,608
	LPG	Euro 1	LPG	LD Euro 1 – 93/59/EEC	1 230	535	197	0
		Euro 2	LPG	LD Euro 2 – 96/69/EEC	1 200	400	87,6	0
		Euro 3	LPG	LD Euro 3 – 98/69/EC Stage2000	2 680	239	37,6	0
		Euro 4	LPG	LD Euro 4 – 98/69/EC Stage2005	994	54,1	21,5	0
		Unabated	LPG	Conventional	3 210	229	1730	0

Buses

Emission factor					Pollutant			
					CO	NMVOC	NO_X	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
Buses	Diesel	Euro 1	Coaches Articulated > 18 t	HD Euro I – 91/542/EEC Stage I	119	40	519	23,2
			Coaches Standard < =18 t	HD Euro I – 91/542/EEC Stage I	178	60	779	34,8
			Urban Buses Articulated > 18 t	HD Euro I – 91/542/EEC Stage I	136	35,4	506	24
			Urban Buses Midi < =15 t	HD Euro I – 91/542/EEC Stage I	204	53,1	759	36
			Urban Buses Standard 15–18 t	HD Euro I – 91/542/EEC Stage I	204	53,1	759	36
		Euro 2	Coaches Articulated > 18 t	HD Euro II – 91/542/EEC Stage II	103	26,8	577	10,6
			Coaches Standard < =18 t	HD Euro II – 91/542/EEC Stage II	155	40,2	865	15,9
			Urban Buses Articulated > 18 t	HD Euro II – 91/542/EEC Stage II	127	24,1	557	11,5
			Urban Buses Midi < =15 t	HD Euro II – 91/542/EEC Stage II	191	36,2	836	17,2
			Urban Buses Standard 15–18 t	HD Euro II – 91/542/EEC Stage II	191	36,2	836	17,2
		Euro 3	Coaches Articulated > 18 t	HD Euro III – 2000 Standards	114	23,8	448	10,6
			Coaches Standard < =18 t	HD Euro III – 2000 Standards	171	35,7	671	15,9
			Urban Buses Articulated > 18 t	HD Euro III – 2000 Standards	133	20,3	466	10,3
			Urban Buses Midi < =15 t	HD Euro III – 2000 Standards	199	30,4	698	15,4
			Urban Buses Standard 15–18 t	HD Euro III – 2000 Standards	199	30,4	698	15,4
		Euro 4	Coaches Articulated > 18 t	HD Euro IV – 2005 Standards	9,44	1,32	284	2,23
			Coaches Standard < =18 t	HD Euro IV – 2005 Standards	14,2	1,98	426	3,34
			Urban Buses Articulated > 18 t	HD Euro IV – 2005 Standards	11,7	1,15	284	2,42
			Urban Buses Midi < =15 t	HD Euro IV – 2005 Standards	17,6	1,73	427	3,64
			Urban Buses Standard 15–18 t	HD Euro IV – 2005 Standards	17,6	1,73	427	3,64
		Unabated	Coaches Articulated > 18 t	Conventional	134	38,9	624	27,7
			Coaches Standard < =18 t	Conventional	200	58,4	936	41,5
			Urban Buses Articulated > 18 t	Conventional	242	84,4	700	38,5
			Urban Buses Midi < =15 t	Conventional	363	127	1 050	57,8
			Urban Buses Standard 15–18 t	Conventional	363	127	1 050	57,8

Heavy duty trucks

Emission factor					Pollutant			
					CO	NMVOC	NO_X	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
Heavy Duty Trucks	Diesel	Euro 1	Articulated 14–20 t	HD Euro I – 91/542/EEC Stage I	105	31,7	525	20,4
			Articulated 20–28 t	HD Euro I – 91/542/EEC Stage I	110	31,9	534	21,1
			Articulated 28–34 t	HD Euro I – 91/542/EEC Stage I	167	46,4	801	31,7
			Articulated 34–40 t	HD Euro I – 91/542/EEC Stage I	184	50,1	874	34,8
			Articulated 40–50 t	HD Euro I – 91/542/EEC Stage I	233	61,5	1 090	43,6
			Articulated 50–60 t	HD Euro I – 91/542/EEC Stage I	311	80,1	1 440	58
			Rigid < =7,5 t	HD Euro I – 91/542/EEC Stage I	146	43	750	28,7
			Rigid > 32 t	HD Euro I – 91/542/EEC Stage I	169	45,2	802	31,8
			Rigid 12–14 t	HD Euro I – 91/542/EEC Stage I	148	47,2	768	29,1
			Rigid 14–20 t	HD Euro I – 91/542/EEC Stage I	158	47,6	787	30,6
			Rigid 20–26 t	HD Euro I – 91/542/EEC Stage I	165	47,8	801	31,6
			Rigid 26–28 t	HD Euro I – 91/542/EEC Stage I	167	46,4	801	31,7
			Rigid 28–32 t	HD Euro I – 91/542/EEC Stage I	167	46,4	801	31,7
			Rigid 7,5–12 t	HD Euro I – 91/542/EEC Stage I	147	45,5	761	28,9

Heavy duty trucks (cont.)

Emission factor					**Pollutant**			
					CO	NMVOC	NO_X	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
		Euro 2	Articulated 14–20 t	HD Euro II – 91/542/EEC Stage II	96,2	21	566	10,9
			Articulated 20–28 t	HD Euro II – 91/542/EEC Stage II	101	21,1	576	11,3
			Articulated 28–34 t	HD Euro II – 91/542/EEC Stage II	152	30,6	857	17,3
			Articulated 34–40 t	HD Euro II – 91/542/EEC Stage II	168	32,9	932	19
			Articulated 40–50 t	HD Euro II – 91/542/EEC Stage II	211	40,3	1 150	23,9
			Articulated 50–60 t	HD Euro II – 91/542/EEC Stage II	279	52	1 510	31,7
			Rigid < =7,5 t	HD Euro II – 91/542/EEC Stage II	125	28,5	809	14,1
			Rigid > 32 t	HD Euro II – 91/542/EEC Stage II	153	29,6	850	17,6
			Rigid 12–14 t	HD Euro II – 91/542/EEC Stage II	136	31,1	826	15,6
			Rigid 14–20 t	HD Euro II – 91/542/EEC Stage II	144	31,4	848	16,4
			Rigid 20–26 t	HD Euro II – 91/542/EEC Stage II	151	31,7	864	16,9
			Rigid 26–28 t	HD Euro II – 91/542/EEC Stage II	152	30,6	857	17,3
			Rigid 28–32 t	HD Euro II – 91/542/EEC Stage II	152	30,6	857	17,3
			Rigid 7,5–12 t	HD Euro II – 91/542/EEC Stage II	131	30,1	820	15
		Euro 3	Articulated 14–20 t	HD Euro III – 2000 Standards	101	19,1	432	8,91
			Articulated 20–28 t	HD Euro III – 2000 Standards	106	19,8	446	9,24
			Articulated 28–34 t	HD Euro III – 2000 Standards	159	28,4	665	13,6
			Articulated 34–40 t	HD Euro III – 2000 Standards	176	31,1	729	15
			Articulated 40–50 t	HD Euro III – 2000 Standards	222	38,4	911	18,7
			Articulated 50–60 t	HD Euro III – 2000 Standards	297	50,4	1 210	24,7
			Rigid < =7,5 t	HD Euro III – 2000 Standards	129	25,4	581	12,5
			Rigid > 32 t	HD Euro III – 2000 Standards	159	27,4	661	13,4
			Rigid 12–14 t	HD Euro III – 2000 Standards	140	27,2	620	12,7
			Rigid 14–20 t	HD Euro III – 2000 Standards	151	28,6	648	13,4
			Rigid 20–26 t	HD Euro III – 2000 Standards	159	29,6	669	13,9
			Rigid 26–28 t	HD Euro III – 2000 Standards	159	28,4	665	13,6
			Rigid 28–32 t	HD Euro III – 2000 Standards	159	28,4	665	13,6
			Rigid 7,5–12 t	HD Euro III – 2000 Standards	136	26,5	605	12,6
		Euro 4	Articulated 14–20 t	HD Euro IV – 2005 Standards	7,7	0,787	283	1,75
			Articulated 20–28 t	HD Euro IV – 2005 Standards	8	0,762	292	1,82
			Articulated 28–34 t	HD Euro IV – 2005 Standards	11,8	1,15	440	2,64
			Articulated 34–40 t	HD Euro IV – 2005 Standards	21,5	1,97	809	4,76
			Articulated 40–50 t	HD Euro IV – 2005 Standards	16,1	1,5	606	3,6
			Articulated 50–60 t	HD Euro IV – 2005 Standards	21,5	1,97	809	4,76
			Rigid < =7,5 t	HD Euro IV – 2005 Standards	11	1,17	384	2,48
			Rigid > 32 t	HD Euro IV – 2005 Standards	11,6	1,15	441	2,56
			Rigid 12–14 t	HD Euro IV – 2005 Standards	10,9	1,23	408	2,48
			Rigid 14–20 t	HD Euro IV – 2005 Standards	11,5	1,18	425	2,62
			Rigid 20–26 t	HD Euro IV – 2005 Standards	12	1,14	438	2,73
			Rigid 26–28 t	HD Euro IV – 2005 Standards	11,8	1,15	440	2,64
			Rigid 28–32 t	HD Euro IV – 2005 Standards	11,8	1,15	440	2,64
			Rigid 7,5–12 t	HD Euro IV – 2005 Standards	11	1,21	399	2,48
		Unabated	Articulated 14–20 t	Conventional	145	45,1	702	26,9
			Articulated 20–28 t	Conventional	119	30	660	25,8
			Articulated 28–34 t	Conventional	177	43,3	997	38,5
			Articulated 34–40 t	Conventional	173	36	1 050	40,9
			Articulated 40–50 t	Conventional	197	33,7	1 280	49,9
			Articulated 50–60 t	Conventional	235	30	1 650	64,5
			Rigid < =7,5 t	Conventional	346	200	878	62,2
			Rigid > 32 t	Conventional	176	41,8	1 000	38,4
			Rigid 12–14 t	Conventional	272	99	1 140	42,7
			Rigid 14–20 t	Conventional	218	67,7	1 050	40,4
			Rigid 20–26 t	Conventional	179	45	990	38,7
			Rigid 26–28 t	Conventional	177	43,3	997	38,5
			Rigid 28–32 t	Conventional	177	43,3	997	38,5
			Rigid 7,5–12 t	Conventional	302	140	1 030	50,6

Motorcycles

Emission factor						**Pollutant**		
					CO	NMVOC	NO_x	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
Motorcycles	Gasoline	Euro 1	2-stroke > 50 cm³	Mot – Euro I	14800	5280	25,4	58
			4-stroke < 250 cm³	Mot – Euro I	8500	675	278	8,75
			4-stroke > 750 cm³	Mot – Euro I	4900	728	281	6,8
			4-stroke 250–750 cm³	Mot – Euro I	8650	746	299	8,78
		Euro 2	2-stroke > 50 cm³	Mot – Euro II	11100	1830	103	31,8
			4-stroke < 250 cm³	Mot – Euro II	4480	525	198	2,19
			4-stroke > 750 cm³	Mot – Euro II	3480	483	154	1,7
			4-stroke 250–750 cm³	Mot – Euro II	4500	576	199	2,19
		Euro 3	2-stroke > 50 cm³	Mot – Euro III	3540	1050	363	12,5
			4-stroke < 250 cm³	Mot – Euro III	1890	291	121	2,19
			4-stroke > 750 cm³	Mot – Euro III	1470	285	94,2	1,7
			4-stroke 250–750 cm³	Mot – Euro III	1900	339	122	2,19
		Euro 4	2-stroke > 50 cm³	Mot – Euro III	3540	1050	363	12,5
			4-stroke < 250 cm³	Mot – Euro III	1890	291	121	2,19
			4-stroke > 750 cm³	Mot – Euro III	1470	285	94,2	1,7
			4-stroke 250–750 cm³	Mot – Euro III	1900	339	122	2,19
		Unabated	2-stroke > 50 cm³	Conventional	16500	6780	45,6	109
			4-stroke < 250 cm³	Conventional	23100	1450	159	9,88
			4-stroke > 750 cm³	Conventional	10600	1390	124	7,05
			4-stroke 250–750 cm³	Conventional	15500	1010	141	8,45

Mopeds

Emission factor						**Pollutant**		
					CO	NMVOC	NO_x	$PM_{2.5}$
Vehicle Type	Fuel	Policy	Vehicle Class	TechnologyBrief	g/GJ	g/GJ	g/GJ	g/GJ
Mopeds	Gasoline	Euro 1	< 50 cm³	Mop – Euro I	8430	4240	30,1	114
		Euro 2	< 50 cm³	Mop – Euro II	2430	3100	485	70,1
		Euro 4	< 50 cm³	Mop – Euro II	2430	3100	485	70,1
		Unabated	< 50 cm³	Conventional	12500	12500	18,1	170

Annex 3 Eurostat energy data products used in the analysis of the industrial (power plant) sector

Data on fuel consumption by the energy and manufacturing industry sector as a whole in each country were obtained from Eurostat (March 2008) and were used to define the activity rates used in the emission calculations. The data are also available for non-EU countries, such as Turkey. The Eurostat data provide the amount of fuel (per fuel type) that is consumed per country per year within these fossil-fuel-driven sectors. These data have been checked against GAINS data and both datasets have been found to be consistent with each other. The energy indicators 101021, 101022, 101307 and 101800 were used to represent total fuel consumption.

- Indicator 101021 consists of fuels transformed into electricity and heat (if any) in public thermal power stations. Public supply thermal power stations are defined as undertakings that generate electricity (and heat) for sale to third parties as their primary activity. They may be privately or publicly owned.

- Indicator 101022 consists of fuels transformed into electricity as well as the part of fuels used for heat sold to third parties (combined heat and power plants) by auto producer thermal power stations. Auto producer thermal power stations are defined as undertakings that support their primary activity. Fuels used for combustion but not as feedstock were taken into account in the analysis. Power plants driven by nuclear and renewable energy sources have not been included in the analysis.

- Indicator 101307 covers all quantities consumed in refineries, excluding losses of refining but including electrical energy consumption for the functioning of the installations. However, quantities of fuels consumed in power plants in refineries are to be classified as transformation input in auto producer power plants (indicator 101022).

Indicator 101800 covers the consumption in all industrial sectors with the exception of the 'Energy sector' (see indicator 101300). The fuel quantities transformed in the electrical power stations of industrial auto producers and the quantities of coke transformed into blast-furnace gas are not entered under overall industrial consumption but under transformation input (see indicator 101022, Input to auto producers thermal power stations, and indicator 101006, Input to blast-furnace plants).

Annex 4 Technologies and emission factors for industrial combustion

Sector	Scenario	Fuel	EF (g/GJ)	
			NO_X	SO_2
Public electricity and heat production	Unabated	Solid fuels	485	1239
Public electricity and heat production	Unabated	Liquid fuels	1130	1750
Public electricity and heat production	Unabated	Gaseous fuels	250	25
Public electricity and heat production	BAT associated AELs	Solid fuels	100	150
Public electricity and heat production	BAT associated AELs	Liquid fuels	50	100
Public electricity and heat production	BAT associated AELs	Gaseous fuels	20	3
Petroleum refining	Unabated	Solid fuels	260	1239
Petroleum refining	Unabated	Liquid fuels	256	1750
Petroleum refining	Unabated	Gaseous fuels	200	167
Petroleum refining	BAT associated AELs	Solid fuels	100	150
Petroleum refining	BAT associated AELs	Liquid fuels	50	100
Petroleum refining	BAT associated AELs	Gaseous fuels	20	3
Manufacturing industries and construction	Unabated	Solid fuels	270	1239
Manufacturing industries and construction	Unabated	Liquid fuels	200	1250
Manufacturing industries and construction	Unabated	Gaseous fuels	190	13
Manufacturing industries and construction	BAT associated AELs	Solid fuels	100	150
Manufacturing industries and construction	BAT associated AELs	Liquid fuels	50	100
Manufacturing industries and construction	BAT associated AELs	Gaseous fuels	20	3

Sources for the emission factors:

- For the unabated scenario, emission factors are taken as the maximum emission factor in the IIASA GAINS model, assuming that this accounts for the unabated technology. For SO_2, a representative factor is chosen, since the factors are very much influenced by the sulphur content in the fuel.
- For the BAT associated AELs, emission factors are taken from a previous EEA study concerning implementation of best available techniques and AELs as specified in the BREF for large combustion plants (EEA, 2008b).

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