REanalysis of the TROpospheric chemical composition over the past 40 years
A long-term modelling study of tropospheric chemistry

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Work Package 5

Analysis of past and present policy response to trends in European air pollution
Deliverable D5.5

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1.Introduction

1.1 DPSIR approach

One way of structuring the analysis of environmental problems and the policy responses to it is provided by the so-called DPSIR approach (Figure 1) or the causal chain for environmental pollution:

DRIVERS represent the economic and societal activities that can be seen as causing PRESSSURES to the environment ("emissions" or "resource (energy, materials, etc) use"). Once these pressures have occurred, they will influence the STATE of the environment (concentrations, depletion of natural resources etc.). This deteriorating state of the environment on its turn leads to IMPACTS or effects to human health, ecosystems materials and reservoirs of natural resources. RESPONSE then stands for the response of decision makers at all levels, from individuals to management of business to policy makers, trying to avoid or decrease unwanted deterioration of the state of the environment or effects.

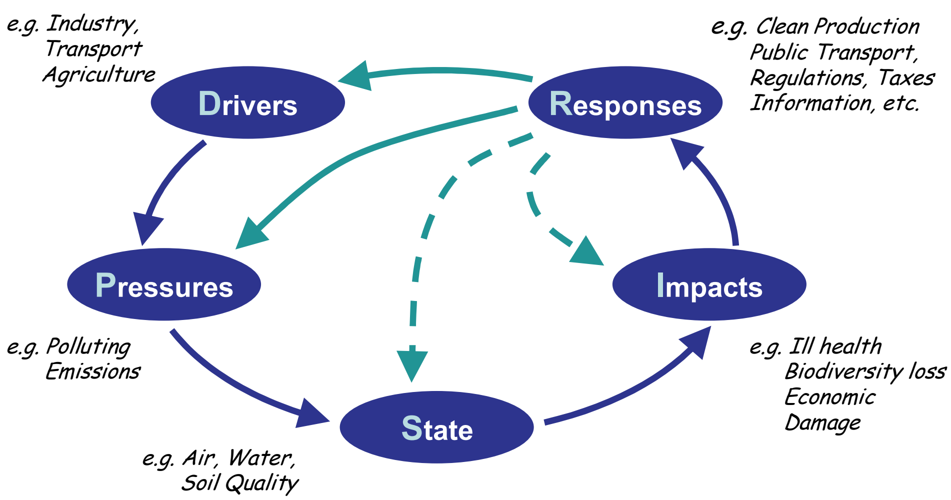


Figure 1 the so-called DPSIR approach

The DPSIR approach clearly sets the stage for an analysis of the effectiveness of POLICIES & MEASURES in terms of alleviating the unwanted impacts of air pollution.

POLICIES & MEASURES or the RESPONSE in terms of DPSIR can in the field of air pollution be directed towards:

- the "DRIVERS": economic/industrial policies or influencing transportation demand
- the "PRESSURES" through technological measures, permits and emission standards, modal shifts in transportation
- the "STATE" through influencing dispersion by high stacks
- the "IMPACTS" by careful physical planning or counter-actions like "liming".

Of these the first two could be seen as "ABATEMENT" measures, whereas the last two could be seen as "ADAPTATION". Within this RETRO study we concentrate on policy and measures directed towards the drivers and the pressures. The study starts with an overview of "ABATEMENT" measures in Europe over the past 40 years. We then discuss the setup of some scenario and sensitivity studies related to changes in important and relevant drivers and pressures. The "STATE" of the environment resulting from the different scenarios is calculated by the models taking part in RETRO. From these calculations we evaluate whether the measures have reached their intended goal. We also study possible effects of tougher legislation and an alternative which are the effects if no measures were taken. The scenario studies also try to evaluate the potential that the specific measures have for further reductions in concentrations of air pollutants.

2. Policies & Measures concering reduction of air pollution in Europe the past 40 years

2.1 Legislation concerning nitrogen oxides.

2.1.1 National emission ceilings for NO_x emissions.

The Sofia Protocol (NO_x Protocol) from 1988 was the first protocol of the Convention on Long-Range Transboundary Air Pollution (LRTAP). The "Protocol concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes" entered into force in 1991. It has been ratified or accepted by 29 countries and the European Community. According to article 2.1 of the Protocol national annual emissions of nitrogen oxides should within 1994 not exceed the emissions in 1987. The national emission ceilings are presented in Table 1.

The next LRTAP protocol, the Gothenburg Protocol was adopted in 1999. The "Protocol to Abate Acidification, Eutrophication and Ground-level Ozone" was signed or joined in total by 32 countries and the European Community. It entered into force on 17 May 2005. In January 2006 the Protocol was ratified by 19 countries and the European Community. The protocol sets national emission ceilings for 2010 for NO_x, VOC, sulphur and ammonia. Parties whose emissions have a more severe environmental or health impact and whose emissions are relatively cheap to reduce will have to make the biggest cuts. Once the Protocol is fully implemented, Europe's NO_x emissions should be cut by at least 41% compared to 1990. The national NO_x emission ceilings established in Annex II of the Protocol are presented in Table 1.

Directive 2001/81/EC (NEC Directive) established national emissions ceilings for NO_x, VOC, SO_2 and NH_3 for 15 European Union countries. According to the Directive member states of European Union, by the year 2010 at the latest, shall limit their annual national emissions to amounts not greater than the emission ceilings laid down in the table below (presented in Annex I of the Directive). The Treaty of Accession from 2003 assigned NEC limits for the 10 new EU countries. National emission ceilings established in Directive 2001/81/EC are equal or a little lower than ceilings for EU countries in Gothenburg Protocol.

Table 1: National Emission Ceilings for nitrogen oxides from Sofia and Gothenburg Protocols to LRTAP and Directive 2001/81/EC, thousand of tonnes of NO_2 /year

Country	Emission in base year 1987 [EMEP,2004	Emission in year 1990 [1]	Sofia Protocol target for 1994 = emission in 1987 [EMEP,2004]	Emission in 1994 [EMEP,2004]	Gothenburg Protocol target for 2010	NEC Directive target for 2010
Armenia	24	46	-	12	*46 **	-
Austria	225	194	*225*	194	*107 **	*103*
Belarus	263	285	*263*	203	*255*	-
Belgium	338	339	*338*	333	*181 **	*176*
Bulgaria	416	361	*416*	230	*266*	-
Croatia	79	87	-	66	*87 **	-
Cyprus	16	18 [2]	*16*	20	-	*23*
Czech Republic	816	742	*816*	375	*286*	*286*
Denmark	319	282	*319*	292	*127*	*127*
Estonia	70	68 [2]	*70*	41	-	*60*
Finland	288	300	*288*	282	*170*	*170*
France	1838	1882	*1838*	1742	*860 **	*810*
Germany	3350	2693	*3350*	2129	*1081*	*1051*
Greece	285	343	*285*	299	*344 **	*344*
Hungary	265	238	*265*	187	*198 **	*198*
Ireland	115	115	*115*	115	*65 **	*65*
Italy	1822	1938	*1822*	1813	*1000 **	*990*
Latvia	83	93	-	49	*84*	*61*
Liechtenstein	0.59 [3]	0.63	*0.59* [3]	0.44 [3]	*0.37**	-
Lithuania	171	158	-	77	*110*	*110*
Luxembourg	20	23	*20*	23	*11*	*11*
Malta	.	10 [4]	-	11 [4]	-	*8*
Netherlands	599	580	*599*	510	*266*	*260*
Norway	230	218	*230*	219	*156*	-
Poland	1530	1280	*1530 **	1105	*879 **	*879*
Portugal	110	348	-	242	*260*	*250*
Republic of Moldova	128	100	-	46	*90 **	-
Romania	580	546	-	319	*437*	-
Russian Federation (European part)	3411	3600	*3411*	2667	-	-
PEMA in Russian Federation	.	360	-	.	*265*	-
Slovakia	197	225	*197*	164	*130*	*130*
Slovenia	57	62	-	66	*45*	*45*
Spain	1059	1113	*1059*	1257	*847*	*847*
Sweden	437	338	*437*	308	*148*	*148*
Switzerland	174	166	*174*	124	*79 **	-
Ukraine	1094	1888	*1094*	568	*1222 **	-
United Kingdom	2734	2673	*2734*	2311	*1181*	*1167*
European Community (EU-12)	12589	12329)	*12479*	11066	-	-
European Community (EU-15)	13539	13161	-	11850	*6671*	*6519*

* Protocol not ratified by country (as of January 2006)

Note: national emission ceilings for 2010 from Directive 2001/81/EC for new EU countries are temporary
[1] emission levels in 1990 presented in Annex II to Gothenburg Protocol
[2] data for 1990 from EMEP [2004]
[3] data for 1987 and 1994 from [Liechtenstein, 2002]
[4] data for 1990 and 1994 from EEA [2005]

EU-25	16744	(16055)	-	13945	-	*8319*

2.1.2 Ceilings for emission of NO_x from large stationary sources

Directive 88/609/EEC laid down two phases of ceilings and targets for reduction of NO_x and SO_2 from existing large combustion plants - with original construction licence granted before 1 July 1987. At first emission ceilings for 12 countries of European Economic Community were established, for NO_x in Annex II. In this directive Member States should take appropriate measures to compliance with the emission limit values from 1990 with respect of SO_2, NO_x and dust. Due to amendment by Directive 90/656/EEC (transitional measures for East Germany) united Germany could comply new values for year 1993 by 1 January 1996. Additionally the Treaty of Accession from 1994 assigned emission ceilings for three new EU countries (Austria, Finland and Sweden). The ceilings and reduction targets for emissions of nitrogen oxides from existing large combustion plants are presented in Table 2. For Greece, Ireland and Portugal increase of emission have been permitted.

The next Large Combustion Plants Directive 2001/80/EC, repeated in Annex II emission ceilings for 15 EU countries. The Treaty of Accession from 2003 added ceilings for 10 new EU countries as real emissions in years 1993 and 1998. The Treaty established also emission ceilings for large combustion plants during a transitional period: for Poland (in year 2008 – 254 kt/a, year 2010 – 251 kt/a, year 2012 – 239 kt/a) and Lithuania (in year 2005 – 4.6 kt/a, year 2008 – 5 kt/a, year 2010 – 10.5 kt/a, year 2012 – 10.8 kt/a). The Directive established new limit values from 2008, for new and existing plants – see Table 3. There are also transition periods for implementation of NO_x emission limit values in new EU Member States: for 21 plants in Poland until 2017, 3 plants in Estonia and 4 plants in Lithuania to 2015, 3 plants in Slovakia to 2007 and for 8 plants in Hungary to mid 2004.

The LRTAP Gothenburg Protocol also applies limit values for emissions from other stationary sources (Annex V of Protocol). Limit values for existing boilers (constructed before 17 May 2006) are compatible with Directive 88/609/EEC requirements for year 1990. Limit values for new boilers and turbines (constructed after 17 May 2006) are compatible with the most restrictive requirements of Directive 2001/80/EC. Only for solid and liquid fuel boilers with 100-300 MW the standards are milder. Annex V added its own standards for existing combustion turbines.

Table 2: Ceilings and reduction targets for emissions of nitrogen oxides from existing large combustion plants (with original construction licence granted before 1 July 1987).

Member State	NO_x emission in year 1980 (ktonnes of NO_2 /year)	NO_x emission ceilings (ktonnes of NO_2 /year)		% reduction/increase over 1980 emissions	
		Phase 1	Phase 2	Phase 1	Phase 2
		1993*	1998	1993*	1998
Belgium	110	88	66	*- 20*	*- 40*
Denmark	124	121	81	*- 3*	*- 35*
Germany	870	696	522	*- 20*	*- 40*
Greece	36	70	70	*+ 94*	*+ 94*
France	400	320	240	*- 20*	*- 40*
Ireland	28	50	50	*+ 79*	*+ 79*
Italy	580	570	428	*- 2*	*- 26*
Luxembourg	3	2.4	1.8	*- 20*	*- 40*
Netherlands	122	98	73	*- 20*	*- 40*
Portugal	23	59	64	*+ 157*	*+ 178*
Spain	366	368	277	*+ 1*	*- 24*
United Kingdom	1 016	864	711	*- 15*	*- 30*
2 Countries accessed to EU on 1 January 1995					
Austria	19	15	11	*- 20*	*- 40*
Finland	81	65	48	*- 20*	*- 40*
Sweden	31	25	19	*- 20*	*- 40*
3 Countries accessed to EU on 1 May 2004					
Cyprus	3	5	6	*+ 67*	*+ 100*
Hungary	68	33	34	*- 51*	*- 49*
Czech Republic	403	228	113	*- 43*	*- 72*
Estonia	20	10	12	*- 52*	*- 40*

Latvia	10	10	9	*- 4*	*- 10*
Lithuania	21	8	11	*- 62*	*- 48*
Malta	1.7	7	2.5	*+ 299*	*+ 51*
Poland	698	426	310	*- 39*	*- 56*
Slovakia	141	85	46	*- 40*	*- 67*
Slovenia	17	15	16	*- 12*	*- 6*

[*] Member States could for technical reasons delay for up to two years the Phase 1 date for reduction in NO_x emissions by notifying the Comission within one month of the notification of this Directive.

Table 3. Emission limit values for NO_x (measured as NO_2) for new large combustion plants due to directives 88/609/EEC and 2001/80/EC.

Type of fuel, rated thermal input of installation	Limit values (mg/Nm^3)			
	Directive 88/609/EEC	***3.1 Directive 2001/80/EC***		
	Plants with licences of construction after 1 July 1987 (1)	All plants with licences of construction before 27 November 2002 and provided into operation to 27 November 2003		Rest of plants
	from 1 July 1990	from 1 January 2008	from 1 January 2016	from 27 November 2002
Solid fuels whose volatile content is less than 10%	1300	1200	1200 (2)	limit values for solid
Solid 50-100 MWth 100-500 MWth > 500 MWth	650	 600 600 500 (600[4])	 600 600 200 (450[5])	 400 200 (300[3]) 200
Liquid 50-100 MWth 100-500 MWth > 500 MWth	450	 450 450 400	 450 450 400	 400 200 (300[6]) 200
Natural gas 50-300 MWth 300-500 MWth > 500 MWth	350	 300 300 200	 300 300 200	 150 100 100
Other gases 50-500 MWth > 500 MWth		 300 200	 300 200	 200 200
Gas Turbines - liquid fuels - natural gas - gaseous fuels	 (200[7]) (150[7])			 120 50-75 120

(1) in East Germany for plants with licences of construction after 1 July 1990
(2) limit value until 1 January 2018
(3) for plants with 100-300 MWth: biomass fuel (Directive 2001/80/EC), all solid fuels (Gothenburg Protocol)
(4) for plants which from 2008 onwards do not operate more than 2000 hours a year
(5) for plants which do not operate more than 1500 hours a year
(6) in Gothenburg Protocol limit value for new plants (constructed after 17 May 2006) with 100-300 MWth
(7) in Gothenburg Protocol limit value for existing plants (constructed before 17 May 2006)

Directive 2000/76/EC on the incineration of waste established limit values for NOx emission – general limit values (in Annex V) and for co-incineration of waste (in Annex II) – see tables 4. and 5. Limit values for new plants are valid from 28 December 2002, for existing plants – from 28 December 2005. The Gothenburg Protocol also established limit values for NOx emissions from cement production, new stationary engines, primary iron and steel production and nitric acid production.

Table 4 General emission limit values for NO_x for waste incineration plants due to Directive 2000/76/EC.

Type of limit value	NO and NO_2 expressed as nitrogen dioxide (mg/m^3)		
	for existing incineration plants		for new incineration plants
	≤ 6 t/h	> 6 t/h	
	from 28 December 2005		*from 28 December 2002*
Daily average value	400	200	200
Half-hourly average value		400 (100%), 200 (97%)	400 (100%), 200 (97%)

Until 1 January 2007 the emission limit does not apply to plants only incinerating hazardous waste.

Table 5. Emission limit values for NO_x for the co-incineration of waste due to Directive 2000/76/EC.

	Daily average values (mg/Nm^3)		
	50-100 MWth	100-300 MWth	>300 MWth
for solid fuels	400	300	200
for biomass	350	300	300
for liquid fuels	400	300	200

Until 1 January 2007 the emission limit does not apply to plants only co-incinerating hazardous waste.

2.1.3. Limit values for emission of NO_x from mobil sources.

Passenger cars

Directive 77/102/EEC amending Directive 70/220/EEC was the first regulation in the European Economic Community concerning emissions of NO_x. It laid down the limit values for emissions from positive-ignition engines of motor vehicles (g/test) for two tests. Limit values were reduced by Directive 78/665/EEC. Directive 83/351/EEC laid down new limit values expressed as the combined mass of the hydrocarbons and nitrogen oxides. These standards have been extended to vehicles with compresion-ignition engines. Changes of limit values are presented in table 6.

Table 6. Limit values for emissions of NO_x from motor vehicles in years 1977-1983 for type I test in amendments of Directive 70/220/EEC.

Reference weight Pr or reference mass RM [kg]	Type I test (verifying the average emission of gaseous pollutants in a congested urban area after a cold start)			
	mass of NO_x (g NO_2/test)		**g HC + NO_x/ test**	
	Directive 77/102/EEC	Directive 78/665/EEC	Sum appriopriate to Directive 78/665/EEC	Directive 83/351/EEC
	1 Oct 1976	1 Oct 1979 (1) 1 Oct 1981 (2)		1 Oct 1984 (1) 1 Oct 1986 (2)
400 < Pr ≤ 750	10.0	8.5	*14.5*	*19.0*
750 < Pr ≤ 850	10.0	8.5	*14.8*	
850 < Pr ≤ 1 020	10.0	8.5	*15.0*	
1 020 < Pr ≤ 1 250	12.0	10.2	*17.3*	*20.5*
1 250 < Pr ≤ 1 470	14.0	11.9	*19.5*	*22.0*
1 470 < Pr ≤ 1 700	14.5	12.3	*20.4*	*23.5*
1 700 < Pr ≤ 1 950	15.0	12.8	*21.6*	*25.0*
1 950 < Pr ≤ 2 150	15.5	13.2	*22.3*	*26.5*
2 150 < Pr ≤ 3 500	16.0	13.6	*23.2*	*28.0*

(1) term for national type-approval
(2) term for prohibit the entry into service of vehicles

Directive 88/76/EEC laid down new limit values for tests dependant on capacity of engine. More stringent European standards for motor vehicles below 1400 cm^3 were introduced by Directive 89/458/EEC – see below.

Table 7. Limit values for emissions of NO_x from motor vehicles in years 1988-1989 for type I test in amendments of Directive 70/220/EEC.

Capacity of engine C [cm^3]	Type I test (verifying the average emission of gaseous pollutants after a cold start)

	g HC + NO_x/ test		**g NO_x/ test**			
	Directive 88/76/EEC	Directive 89/458/EEC	Directive 88/76/EEC	Directive 89/458/EEC	Terms for:	
					Directive 88/76/EEC	Directive 89/458/EEC
C > 2 000	*6.5*	*6.5*	3.5	3.5	1 Oct 1988/ 1 Oct 1989	1 Oct 1988/ 1 Oct 1989
1 400 ≤ C ≤ 2 000	*8.0*	*8.0*	-	-	1 Oct 1991/ 1 Oct 1993	1 Oct 1991/ 1 Oct 1993
C < 1400	*15.0*	*5.0*	6.0	-	1 Oct 1990 1 Oct 1991	1 Jul 1992/ 31 Dec 1992

By Directive 91/441/EEC standards have been extended to all passenger cars independently of their engine capacity on the basis of an improved European test procedure comprising an extra-urban driving cycle (limit values expressed in g/km). Pursuant to Directive 93/59/EEC passenger cars designed to carry more than six occupants and having a maximum mass of more than 2500 kg, light commercial vehicles, and off-road vehicles, which previously benefited from less stringent standards, have since then been subject to standards as stringent as the respective standards for passenger cars.

Table 8. Limit values for emissions of NO_x from motor vehicles after 1991 for type I test in amendments of Directive 70/220/EEC.

3.1.1 Category of vehicle and reference mass RM [kg]	Fuel: P-Petrol, D-Diesel oil, I -Diesel oil with indirect injection	Type I test (verifying the average emission of gaseous pollutants after a cold start)							
		g HC + NO_x/ km						**g NO_x/km**	
		Euro I		Euro II		Directive 98/69/EC			
		Directive 91/441	Directive 93/59	Directive 94/12/EC	Directive 96/69/EC	Euro III	Euro IV	Euro III	Euro IV
		from: 1992	1993/ 1994	1996/ 1997	1996/ 1997	2000	2005	2000	2005
Category M except: - vehicles designed to carry more than six occupants including the driver, - vehicles whose maximum mass exceeds 2 500 kg	**P**	0.81	0.81	0.50	0.50	-		*0.15*	*0.08*
	D	0.97	0.97	0.70	0.70	0.56	0.30	*0.50*	*0.25*
	I			0.90	0.90				

3.1.1 Category of vehicle and reference mass RM [kg]		Fuel: P-Petrol, D-Diesel oil, I -Diesel oil with indirect injection	Type I test (verifying the average emission of gaseous pollutants after a cold start)							
			g HC + NO_x/ km						**g NO_x/km**	
			Euro I		Euro II		Directive 98/69/EC			
			Directive 91/441	Directive 93/59	Directive 94/12/EC	Directive 96/69/EC	Euro III	Euro IV	Euro III	Euro IV
			from: 1992	1993/ 1994	1996/ 1997	1996/ 1997	2000	2005	2000	2005
N_1 and remaining vehicles of category M	Class I (RM≤1250) [1])	**P**	-	0.81	0.81	0.50	-		*0.15*	*0.08*
		D		0.97	0.97	0.70	0.56	0.30	*0.50*	*0.25*
		I				0.90				
	Class II (1250< RM≤1700) [2])	**P**		1.17	1.17	0.60	-		*0.18*	*0.10*
		D		1.40	1.40	1.00	0.72	0.39	*0.65*	*0.33*
		I				1.30				
	Class III (1700<RM) [3])	**P**		1.42	1.42	0.70	-		*0.21*	*0.11*
		D		1.70	1.70	1.20	0.86	0.46	*0.78*	*0.39*
		I				1.60				

[1]) in Directive 98/69/EC: RM≤1305
[2]) in Directive 98/69/EC: 1305<RM≤1760
[3]) in Directive 98/69/EC: 1760<MR

Directive 94/12/EC introduced more stringent limit values and a new method for checking on the conformity of production. Complying with directives 94/12/EC and 96/69/EC separate limit values were fixed for petrol-driven and Diesel oil vehicles.

Directive 98/69/EC introduced specific NO_x emission limits for petrol-driven motor vehicles and more stringent limit values for emission of HC+NO_x for Diesel oil vehicles. This directive also introduced a new type VI test to measure emissions at low temperatures.

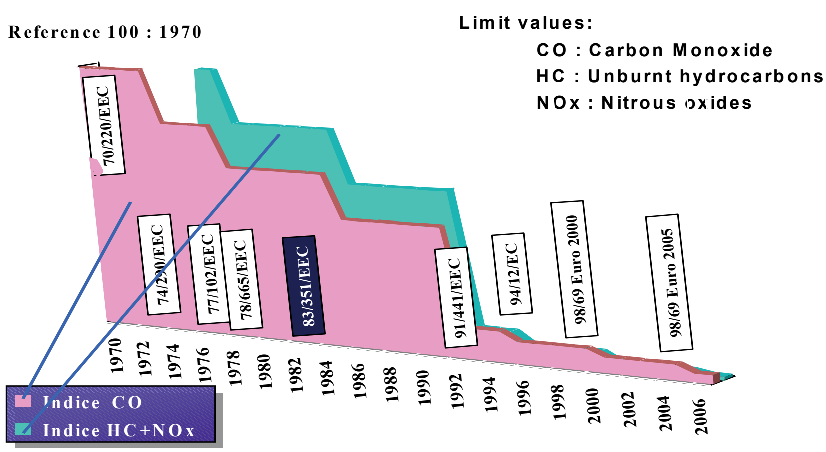
In Directive 98/69/EC reductions of the Type I test limits applicable from the year 2000 have been identified as key measures to achieve sufficient medium-term air quality, corresponding to a drop of:

- 40% in NO_x for petrol-driven passenger cars,

- 20% in the combined value for hydrocarbons plus NO_x for indirect injection diesel passenger cars,
- 40% in NO_x and in HC+NO_x for direct-injection diesel passenger cars,
- 20% in NO_x for diesel light commercial vehicles,

Succeeding directives concerning reduction of NO_x, unburnt hydrocarbons and CO gave more restrictive limit value for new cars. Directive 91/441/EEC was the greatest step – see figure below. Directive 99/102/EC clarified additional the On-Board Diagnostic (OBD) systems requirements for motor vehicles. Directive 2001/100/EC set low temperature emission limits. This directive also exempted vehicles with positive-ignition engines that run only on gas fuel (LPG or NG) from the low temperature test.

Figure 1. Changes of limit values according to amendments of Directive 70/220/EC, Source: (Renault, 2005)



Heavy duty vehicles

Directive 88/77/EC established limit values for heavy duty vehicles (having a total mass exceeding 3.5 tonnes). It was amended by Directive 91/542/EEC in two stages. The first stage (1992/1993) was coinciding with the implementation dates of the new European emission standards for passenger cars. The second stage (1995/1996) established a longer-term orientation for the European motor industry.

Directive 1999/96/EC provided Euro III, IV and V standards and limit values for positive ignition engines fuelled with natural gas or liquefied petroleum gas. Directive 2005/55/EC repeated these limit values – see Table 9. Additionally it requires new heavy-duty engines to comply with new technical requirements covering on-board diagnostic systems.

Reductions in limits applicable from the year 2000 are corresponding to abatements of 30% in the emissions of NO_x. Additional reductions in emission limits applicable from the year 2005, corresponding to additional abatements of 30% in NO_x are expected to contribute to air quality improvement in the medium to longer term. The additional limit for NO_x applicable in the year 2008 should result in a further 43% reduction.

Table 9 Limit values for emissions of NO_x from heavy duty vehicles since 1988 in amendments of Directive 88/77/EEC.

Type of test	**g NO_x/kWh**						
	Directive 88/77/EEC	Directive 91/542/EEC		Directive1999/96/EC and 2005/55/EC			
	Pre Euro I	Euro I	Euro II	Euro III	Euro IV	Euro V	EEV*
	from 1988/ 1990	1992/ 1993	1995/ 1996	2000/ 2001	2005/ 2006	2008/ 2009	
Tests ECE R49 and ESC (European Stationary Cycle)	14.4	8.0	7.0	5.0	3.5	2.0	2.0

Test ETC (European Transient Cycle) - for gas engines		5.0	3.5	2.0	2.0

* EEV – environmentally friendly vehicle

In addition Directive 2002/51/EC included limit values for two-wheel motorcycles, tricycles and quadricycles (for type I test - emissions in a congested urban area).

2.1.4. Concentration of NO_x in ambient air.

Directive 85/203/EC established the first limit values and guide values for nitrogen dioxide for implementation since 1 July 1987 – see table below. For East Germany the deadline for obligation was extented to 31 December 1991 by Directive 90/656/EEC.

Table 10. Limit values and guide values for NO_2 in ambient air due to directive 85/203/EEC.

	Reference period	Value (µg/m^3)	Type of percentyle
Limit value	Calendar year	200	98th percentile calculated from the mean values per hour or per period of less than an hour recorded throughout the year
Guide value	Year	135	
		50	50th percentile calculated from the mean values per hour or per period of less than an hour recorded throughout the year

Directive 1999/30/EC (I Daughter Directive for Air Quality Framework Directive 96/62/EC) established in annex II new limit values and alert threshold – see below.

Table 11. Limit values of nitrogen oxides in ambient air due to Directive 1999/30/EC.

	Averaging period	Limit value	Margin of tolerance (mean the percentage of the limit value by which this value may be exceeded)	Date by which limit value is to be met
Annual limit value for the protection of vegetation	Calendar year	30 $\mu g/m^3$ NO_x	None	19 July 2001
Hourly limit value for the protection of human health	1 hour	200 $\mu g/m^3$ NO_2, not to be exceeded more than 18 times a calendar year	50% on the entry into force of this Directive (July 1999), reducing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0% by 1 January 2010	1 January 2010
Annual limit value for the protection of human health	Calendar year	40 $\mu g/m^3$ NO_2		

Alert threshold (level beyond which there is a risk to human health from brief exposure) was established on level 400 $\mu g/m^3$ NO_2, measured over three consecutive hours at locations representative of air quality over at least 100 km^2 or an entire zone or agglomeration, whichever is the smaller.

2.2 Legislation concerning non-methane volatile organic compounds.

2.2.1. National emission ceilings for VOC emission.

The Geneva Protocol from 1991 was the first protocol of the LRTAP Convention concerning emission of VOC. The „Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes” entered into force on 29 September 1997. It was ratified or accepted by 21 countries.

According to article 2.2 of the protocol countries should control and reduce their national annual emissions of VOC:

a) Reduce annual emissions by at least 30% by the year 1999 (using 1988 levels as a basis or other annual level during the period 1984 to 1990). Austria, Belgium, Estonia, Finland, France, Germany, Netherlands, Portugal[5], Spain, Sweden and the United Kingdom has chosen year 1988 as base year, Denmark – year 1985, Liechtenstein, Switzerland and the United States[5] – year 1984, and Czech Republic, Italy, Luxembourg, Monaco and Slovakia - year 1990 as base year.

b) For countries where annual emission of VOC in 1988 were lower than 500,000 tons and 20kg/inhabitant and 5 tonnes/km^2 (Bulgaria, Greece[5] and Hungary) the emissions should not exceed the 1988 levels by 1999,

c) For TOMAs (Tropospheric Ozone Management Areas) in Canada[5] and Norway specified in Annex I, the annual emissions from these areas should be reduced by at least 30% and national emissions should not exceed the 1988 levels by 1999.

Established national emission ceilings are presented in Table 12. According to article 2.3 countries should apply appropriate national and international standards for new stationary and mobile sources and measures for industrial products.

The Gothenburg Protocol sets national emission ceilings for year 2010. Once the Protocol is fully implemented, Europe's VOC emissions should be cut by at least 40% compared to 1990. The established national emission ceilings in Annex II of the Protocol are presented in Table 12. The Protocol also sets tight limit values for VOC specific stationary emission sources. It entered into force on 17 May 2005.

Directive 2001/81/EC and Treaty of Accession from 2003 established VOC annual national emissions ceilings for 25 European Union countries.

Table 12. National Emission Ceilings from Geneva and Gothenburg Protocols to LRTAP and Directive 2001/81/EC, thousand of tonnes of VOC /year

Country	Emission in base year 1984-1990 [EMEP,2004	Emission in year 1990 [6]	Calculated Geneva Protocol target for 1999	Emission in 1999 [EMEP,2004]	Gothenburg Protocol target for 2010	NEC Directive target for 2010
Armenia	-	81	-	17	*81 **	-
Austria	378	351	*265*	190	*159 **	*159*
Belarus	-	533	-	240	*309*	-
Belgium	274	324	*192*	248	*144 **	*139*
Bulgaria	309	217	*309*	118	*185*	-
Croatia	-	105	-	77	*90 **	-
Cyprus	-	14 [7]	-	14	-	*14*
Czech Republic	441	435	*309*	234	*220*	*220*
Denmark	194	178	*136*	138	*85*	*85*
Estonia	84	88 [7]	*59*	42	-	*49*
Finland	225	209	*158*	166	*130*	*130*
France	2734	2957	*1914*	1806	*1100 **	*1050*
Germany	3256	3195	*2279*	1844	*995*	*995*
Greece	255	373	*255 **	291	*261 **	*261*
Hungary	215	205	*215*	170	*137 **	*137*
Ireland	-	197	-	98	*55 **	*55*
Italy	2041	2213	*1429*	1722	*1159 **	*1159*
Latvia	-	152	-	87	*136*	*136*
Liechtenstein	1.15 [8]	1.56	*0.80*	0.56[8]	*0.86**	-
Lithuania	-	103	-	68	*92*	*92*
Luxembourg	19	20	*13*	15	*9*	*9*
Malta	-	5 [9]	-	10 [9]	-	*12*
Netherlands	538	502	*377*	291	*191*	*185*
Norway	249	310	*249*	368	*195*	-
Poland	-	831	-	731	*800 **	*800*
Portugal	228	640	*160 **	276	*202*	*180*
Republic of Moldova	-	157	-	22	*100 **	-
Romania	-	616	-	638	*523*	-
Russian Federation (European part)	-	3566	-	2451	-	-
PEMA in Russian Federation	-	203	-	.	*165*	-
Slovakia	252	149	*176*	124	*140*	*140*
Slovenia	-	42	-	40	*40*	*40*
Spain	1510	1094	*1057*	1532	*669*	*662*
Sweden	528	526	*370*	318	*241*	*241*
Switzerland	324	292	*227*	165	*144 **	-
Ukraine	-	1396	-	272	*797 **	-
United Kingdom	2438	2555	*1707*	1479	*1200*	*1200*
European Community (EU-12)	13487	(14248)	*9519 **	9740	-	-
European Community (EU-15)	-	15353	-	10414	*6600*	*6510*
EU-25	-	(17377)	-	11934	-	*8150*

* Protocol not ratified by country (to January 2006)

Note: national emission ceilings for 2010 from Directive 2001/81/EC for new EU countries are temporary

[5] country not ratified Geneva Protocol
[6] emission levels in 1990 presented in Annex II to Gothenburg Protocol
[7] data for 1990 from EMEP [2004]
[8] data for 1984 and 1999 from [Liechtenstein, 2002]
[9] data for 1990 and 1999 from EEA [2005]

2.2.2. Limit values for emission of VOC from stationary sources.

Directive 94/63/EC was the first EU law concerning control of VOCs emissions. The Directive laid down requirements for storage of petrol and its distribution from terminals to service stations. In Annex II of the Directive concentration of vapours in the exhausts from the vapour recovery was established. The United Kingdom had 9-years derogation. New EU member states have derogations finally to 2008.

Directive 1999/13/EC laid down limit values for VOCs emissions due to the use of organic solvents in a list of activities. Limit values are expressed in mg C/Nm^3 (for waste gases), g/kg, g/m^2, kg/m^3 or g per rail. New installations and existing installations shall comply thresholds and emission controls described in Annex IIA of the Directive no later than 31 October 2007.

Directive 2004/42/CE set limit values for VOCs emissions due to the use of organic solvents in paints, varnishes and vehicle refinishing products.

The Gothenburg Protocol also sets tight limit values for specific VOCs emission sources and requires best available techniques to be used to keep emissions down. In Annex VI of the Directive limit values for stationary sources are compatible with Directive 1999/13/EC. Limit values for storage and distribution of petrol are more restrictive than in Directive 94/63/EC.

2.2.3. Limit values for emission of hydrocarbons from mobil sources.

Passenger cars

Directive 70/220/EEC was the first regulation in the European Economic Community concerning emissions of unburnt hydrocarbons. It laid down the limit values for emissions from positive-ignition engines of motor vehicles (g/test) for different tests. Subsequently, limit values were reduced by directives 74/290/EEC and 78/665/EEC. Directive 83/351/EEC laid down new limit values expressed as the combined mass of the hydrocarbons and of the nitrogen oxides. Changes of limit values are presented in the table below.

Table 13. Limit values for emissions of hydrocarbons from motor vehicles in years 1970-1983 for type I test in amendments of Directive 70/220/EEC.

Reference weight Pr or reference mass RM [kg]	Type I test (verifying the average emission of gaseous pollutants in a congested urban area after a cold start)				
	g HC/test			**g HC + NO_x/ test**	
	Directive 70/220/EEC	Directive 74/290/EEC	Directive 78/665/EEC	Sum appriopriate to Directive 78/665/EEC	Directive 83/351/EEC
	1 Oct 1970	1 Oct 1976	1 Oct 1979 (1) 1 Oct 1981 (2)		1 Oct 1984 (1) 1 Oct 1986 (2)
400 < Pr ≤ 750	8.0	6.8	6.0	*14.5*	*19.0*
750 < Pr ≤ 850	8.4	7.1	6.3	*14.8*	
850 < Pr ≤ 1 020	8.7	7.4	6.5	*15.0*	
1 020 < Pr ≤ 1 250	9.4	8.0	7.1	*17.3*	*20.5*
1 250 < Pr ≤ 1 470	10.1	8.6	7.6	*19.5*	*22.0*
1 470 < Pr ≤ 1 700	10.8	9.2	8.1	*20.4*	*23.5*
1 700 < Pr ≤ 1 950	11.4	9.7	8.6	*21.6*	*25.0*
1 950 < Pr ≤ 2 150	12.1	10.3	9.1	*22.3*	*26.5*
2 150 < Pr ≤ 3 500	12.8	10.9	9.6	*23.2*	*28.0*

(1) term for national type-approval
(2) term for prohibit the entry into service of vehicles

Directives 88/76/EEC and 89/458/EEC laid down new limit values for tests dependant on capacity of engine – see Table 14.

Table 14. Limit values for emissions of hydrocarbons from motor vehicles in years 1988-1989 for type I test in amendments of Directive 70/220/EEC.

Capacity of engine C [cm^3]	Type I test (verifying the average emission of gaseous pollutants after a cold start)					
	g HC + NO_x/ test					
	Directive 88/76/EEC	Terms for:		Directive 89/458/EEC	Terms for:	
		national type-approval	prohibit the entry into service of vehicles		national type-approval	prohibit the entry into service of vehicles
C > 2 000	*6.5*	1 Oct 1988	1 Oct 1989	*6.5*	1 Oct 1988	1 Oct 1989
1 400 ≤ C ≤ 2 000	*8.0*	1 Oct 1991	1 Oct 1993	*8.0*	1 Oct 1991	1 Oct 1993
C < 1400	*15.0*	1 Oct 1990	1 Oct 1991	*5.0*	1 Jul 1992	31 Dec 1992

Table 15. Limit values for emissions of hydrocarbons from motor vehicles after 1991 for type I test in amendments of Directive 70/220/EEC.

3.1.2 Category of vehicle and reference mass RM [kg]		Fuel: P-Petrol, D-Diesel oil, I -Diesel oil with indirect injection	Type I test (verifying the average emission of gaseous pollutants after a cold start)							
			g HC + NO_x/ km						**g HC/km**	
			Euro I		Euro II		Directive 98/69/EC			
			Directive 91/441	Directive 93/59	Directive 94/12/EC	Directive 96/69/EC	Euro III	Euro IV	Euro III	Euro IV
			from: 1992	1993/ 1994	1996/ 1997	1996/ 1997	2000	2005	2000	2005
Category M except: - vehicles designed to carry more than six occupants including the driver, - vehicles whose maximum mass exceeds 2 500 kg		**P**	0.81	0.81	0.50	0.50			*0.20*	*0.10*
		D	0.97	0.97	0.70	0.70	0.56	0.30		
		I			0.90	0.90				
N_1 and remaining vehicles of category M	Class I (RM≤1250) [1])	**P**		0.81	0.81	0.50			*0.20*	*0.10*
		D		0.97	0.97	0.70	0.56	0.30		
		I				0.90				
	Class II (1250< RM≤1700) [2])	**P**		1.17	1.17	0.60			*0.25*	*0.13*
		D		1.40	1.40	1.00	0.72	0.39		
		I				1.30				
	Class III (1700<RM) [3])	**P**		1.42	1.42	0.70			*0.29*	*0.16*
		D		1.70	1.70	1.20	0.86	0.46		
		I				1.60				

[1]) in Directive 98/69/EC: RM≤1305
[2]) in Directive 98/69/EC: 1305<RM≤1760
[3]) in Directive 98/69/EC: 1760<MR

Directives 91/441/EEC, 93/59/EEC, 94/12/EC, 96/69/EC and 98/69/EC set new limit values and extended it to new types of passenger cars.

In Directive 98/69/EC reductions of the Type I test limits applicable from the year 2000 have been identified as key measures to achieve sufficient medium-term air quality, corresponding to a drop of:

- 40% in total hydrocarbons for petrol-driven passenger cars,
- 20% in the combined value for hydrocarbons plus nitrogen oxides for indirect injection diesel passenger cars,
- 40% in the combined value for hydrocarbons plus nitrogen oxides for direct-injection diesel passenger cars,
- 65% in hydrocarbons for diesel light commercial vehicles,

Directives 99/102/EC and 2001/100/EC added limit values for next tests for passenger cars.

Heavy duty vehicles

Directives 88/77/EC, 91/542/EEC, 1999/96/EC and 2005/55/EC established limit values for heavy duty vehicles. In Directive 1999/96/EC limits for gas engine were established for non-methane hydrocarbons – see below.

Reductions in limits applicable from 2000 are corresponding to abatements of 30% in emissions of hydrocarbons. Additional reductions are applicable from 2005, corresponding to additional abatements of 30% in hydrocarbons.

Table 16. Limit values for emissions of hydrocarbons from heavy duty vehicles since 1988 for amendments of Directive 88/77/EEC.

Type of test	Directive 88/77/EEC	Directive 91/542/EEC		Directive 1999/96/EC and 2005/55/EC			
	Pre Euro I	Euro I	Euro II	Euro III	Euro IV	Euro V	EEV*
	from 1988/ 1990	1992/ 1993	1995/ 1996	2000/ 2001	2005/ 2006	2008/ 2009	

Tests ECE R49 and ESC (European Stationary Cycle)	**g HC/kWh**						
	2.40	1.10	1.10	0.66	0.46	0.46	0.25
Test ETC (European Transient Cycle) - for gas engines	**g NMHC/kWh**						
				0.78	0.55	0.55	0.40

* EEV – environmentally friendly vehicle

Directive 2002/51/EC laid down limit values for two-wheel motorcycles, tricycles and quadricycles.

2.3 Legislation concerning carbon monoxide.

2.3.1 Limit values for emission of CO from stationary sources.

Directives 89/369/EEC and 89/429/EEC established limit value for CO emission from new and existing municipal waste incineration plants. Directive 94/67/EC established limit value for CO emission from incineration of hazardous wastes. Directive 2000/76/EC on the incineration of waste established common limit values for CO emissions.

Table 17 Limit values for emissions of CO from waste incineration plants due to EU directives.

Type of limit value	**CO in combustion gas (mg/m³)**		
	Directives 89/369/EEC and 89/429/EEC	Directive 94/67/EC	Directive 2000/76/EC
	Municipal waste incineration plants	incineration of hazardous wastes	all waste incineration plants
Daily average value	100	50	50
or half-hourly average values		100	100
95% of 10-minute average values		150	150

2.3.2. Limit values for emission of CO from mobil sources.

Passenger cars

Directive 70/220/EEC was the first regulation in the European Economic Community concerning emissions of carbon monoxide. It laid down the limit values for emissions from positive-ignition engines of motor vehicles (g/test) for different tests. In the next years limit values were reduced by directives 74/290/EEC, 78/665/EEC and 83/351/EEC. Changes of limit values are presented in Table 18.

Table 18. Limit values for emissions of CO from motor vehicles in years 1970-1983 for type I test in amendments of Directive 70/220/EEC.

Reference weight Pr or reference mass RM [kg]	Type I test (verifying the average emission of gaseous pollutants in a congested urban area after a cold start)			
	g CO/test			
	Directive 70/220/EEC	Directive 74/290/EEC	Directive 78/665/EEC	Directive 83/351/EEC
	1 Oct 1970	1 Oct 1976	1 Oct 1979 (1) 1 Oct 1981 (2)	1 Oct 1984 (1) 1 Oct 1986 (2)
400 < Pr ≤ 750	100	80	65	58
750 < Pr ≤ 850	109	87	71	
850 < Pr ≤ 1 020	117	94	76	
1 020 < Pr ≤ 1 250	134	107	87	67
1 250 < Pr ≤ 1 470	152	122	99	76
1 470 < Pr ≤ 1 700	169	135	110	84
1 700 < Pr ≤ 1 950	186	149	121	93
1 950 < Pr ≤ 2 150	203	162	132	101
2 150 < Pr ≤ 3 500	220	176	143	110

(1) term for national type-approval
(2) term for prohibit the entry into service of vehicles

Directives 88/76/EEC and 89/458/EEC laid down new limit values for tests dependent on capacity of engine – see below.

Table 19 Limit values for emissions of CO from motor vehicles in years 1988-1989 for type I test in amendments of Directive 70/220/EEC.

Capacity of engine C [cm³]	Type I test (verifying the average emission of gaseous pollutants after a cold start)					
	g CO/test					
	Directive 88/76/EEC	Terms for:		Directive 89/458/EEC	Terms for:	
		national type-approval	prohibit the entry into service of vehicles		national type-approval	prohibit the entry into service of vehicles
C > 2 000	25	1 Oct 1988	1 Oct 1989	25	1 Oct 1988	1 Oct 1989
1 400 ≤ C ≤ 2 000	30	1 Oct 1991	1 Oct 1993	30	1 Oct 1991	1 Oct 1993
C < 1400	45	1 Oct 1990	1 Oct 1991	19	1 Jul 1992	31 Dec 1992

Directives 91/441/EEC, 93/59/EEC, 94/12/EC, 96/69/EC and 98/69/EC laid down new limit values and extended it to next types of passenger cars.

Table 20 Limit values for emissions of CO from motor vehicles in the years after 1991 for type I test in amendments of Directive 70/220/EEC.

3.1.3 Category of vehicle and reference mass RM [kg]		Fuel: P - Petrol, D+I -Diesel oil, with direct and indirect injection	Type I test (verifying the average emission of gaseous pollutants after a cold start)					
			G CO/km					
			Euro I		Euro II		Directive 98/69/EC	
			Directive 91/441/EEC	Directive 93/59/EEC	Directive 94/12/EC	Directive 96/69/EC	Euro III	Euro IV
			From: 1992	1993/ 1994	1996/ 1997	1996/ 1997	2000	2005
Category M except: - vehicles designed to carry more than six occupants including the driver, - vehicles whose maximum mass exceeds 2 500 kg		**P**	2.27	2.27	2.20	2.20	2.30	1.00
		D+I	2.47	2.47	1.00	1.00	0.64	0.50
N_1 and remaining vehicles of cate-gory M	Class I (RM≤1250) [1])	**P**		2.27	2.27	2.20	2.30	1.00
		D+I		2.47	2.47	1.00	0.64	0.50
	Class II (1250< RM≤1700) [2])	**P**		4.75	4.75	4.00	4.17	1.81
		D+I		5.18	5.18	1.25	0.80	0.63

3.1.3 Category of vehicle and reference mass RM [kg]		Fuel: P - Petrol, D+I -Diesel oil, with direct and indirect injection	Type I test (verifying the average emission of gaseous pollutants after a cold start)					
			G CO/km					
			Euro I		Euro II		Directive 98/69/EC	
			Directive 91/441/EEC	Directive 93/59/EEC	Directive 94/12/EC	Directive 96/69/EC	Euro III	Euro IV
			From: 1992	1993/ 1994	1996/ 1997	1996/ 1997	2000	2005
	Class III (1700<RM) 3)	**P**		5.75	5.75	5.00	5.22	2.27
		D+I		6.27	6.27	1.50	0.95	0.74

1) in Directive 98/69/EC: RM≤1305
2) in Directive 98/69/EC: 1305<RM≤1760
3) in Directive 98/69/EC: 1760<MR

In Directive 98/69/EC reductions of the Type I test limits applicable from the year 2000 have been identified as key measures to achieve sufficient medium-term air quality, corresponding to a drop of carbon monoxide emissions of:

- 30% for petrol-driven passenger cars,
- 40% for indirect and direct-injection diesel passenger cars and light commercial vehicles,

Directives 99/102/EC and 2001/100/EC added limit values for next tests for passenger cars.

Heavy duty vehicles

Directives 88/77/EC, 91/542/EEC, 1999/96/EC and 2005/55/EC established limit values for heavy duty vehicles – see Table 21.

Reductions in limits applicable from 2000 are corresponding to abatements of 30 % in emissions of CO. Additional reductions applicable from 2005 correspond to an additional 30 % reduction in CO emissions.

Table 21 Limit values for emissions of CO from heavy duty vehicles since 1988 for amendments of Directive 88/77/EEC.

Type of test	g CO/kWh						
	Directive 88/77/EEC	Directive 91/542/EEC		Directive 1999/96/EC and 2005/55/EC			
	Pre Euro I	Euro I	Euro II	Euro III	Euro IV	Euro V	EEV*
	from 1988/ 1990	1992/ 1993	1995/ 1996	2000/ 2001	2005/ 2006	2008/ 2009	
Tests ECE R49 and ESC (European Stationary Cycle)	11.20	4.50	4.00	2.10	1.50	1.50	1.50
Test ETC (European Transient Cycle) - for gas engines				5.45	4.00	4.00	3.00

* EEV – environmentally friendly vehicle

Directive 2002/51/EC laid down limit values for two-wheel motorcycles, tricycles and quadricycles.

2.3.3. Concentration of CO in ambient air.

Directive 2000/69/EC (II Daughter Directive for Air Quality Framework Directive 96/62/EC) established in annex II limit value for CO – see below.

Table 22 Limit value of CO in ambient air due to Directive 2000/69/EC.

	Averaging period	Limit value	Margin of tolerance (mean the percentage of the limit value by which this value may be exceeded)	Date by which limit value is to be met
Limit value for the protection of	Calendar year	10 mg/m^3	6 mg/m^3 (60%) on 13 December 2000 (the entry into force of this	1 January 2005

human health			Directive), reducing on 1 January 2003 and every 12 months thereafter by 2 mg/m^3 to reach 0% by 1 January 2005	

2.4 Legislation concerning methane emissions.

2.4.1 Reduction targets for emission of greenhouse gases.

The Kyoto Protocol of The United Nations Framework Convention on Climate Change (UNFCCC) from 1997 established reduction commitments for industrialized countries. Generally so-called UNFCCC Annex I countries should reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990. The goal is to lower overall emissions from six greenhouse gases – CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 - calculated in CO_2 equivalent (according to their global warming potential) as an average over the five-year period of 2008-2012.

There are national targets described in Annex B of Kyoto Protocol:

- 8% reductions for the EU-15, Monaco, Liechtenstein, Switzerland, Czech Republic, Estonia, Latvia, Lithuania, Slovakia, Slovenia, Bulgaria and Romania,
- 7% reduction for the United States of America,
- 6% reductions for Hungary, Poland, Canada and Japan,
- 0% reductions for Russian Federation, Ukraine and New Zealand,
- increase of 1% for Norway,
- increase of 8% for Australia,
- increase of 10% for Iceland.

Belarus and Turkey did not sign the Kyoto Protocol. Therefore emission reduction commitments were not defined for them. Other European countries are not UNFCCC Annex I countries.

Year 1990 is the base year for calculation of emission reduction. However according to Decision 9/CP.2 of the Conference of the Parties countries undergoing the process of transition to a market economy can use other periods than 1990 when production and emissions were significantly larger than than in 1990, a year of economic collapse.

The Kyoto Protocol entered into force on 16 January 2005 after ratification by the Russian Federation when countries which had ratified the protocol represented at least 55% of CO_2 emissions by UNFCCC Annex I parties in 1990. Among the 164 countries which signed protocol or later accesed to it, a total of 158 countries had ratified the agreement in January 2006. Notable exceptions include large emitters like the United States of America and Australia. Also Monaco, Croatia (European Annex I countries) and Kazakhstan and Zambia have not ratified the Protocol till now.

According to article 4 of the Protocol a group of Annex I countries can reach an agreement to jointly fulfil their commitments. The European Union is the only regional economic integration organization which used this assignation.

By Council Decision 2002/358/EC members of EU-15 approved the Kyoto Protocol and the joint fullfilment of commitments thereunder. Reduction commitment of 8% for the European Community was unequally divided among the individual states. Following the principle of solidarity, EU member states agreed that countries which have the largest economic gap to eliminate would be able to increase their emissions in 2008-12 with respect to 1990. In contrast, other countries commited to achieve greater reduction – see table 23.

Table 23 Emission limitation or reduction commitments for EU-15.

Country	Reduction commitment or emission limitation (percentage of base year or period)	
	Annex B of the Kyoto Protocol	Annex II to Council Decision 2002/358/CE
The European Community	92 %	
Luxembourg		72 %
Denmark		79 %

Germany		79 %
Austria		87 %
United Kingdom		87.5 %
Belgium		92.5 %
Italy		93.5 %
Netherlands		94 %
Finland		100 %
France		100 %
Sweden		104 %
Ireland		113 %
Spain		115 %
Greece		125 %
Portugal		127 %

Directive 2003/87/EC established a scheme for greenhouse gas emission allowance trading. The European Union Greenhouse Gas Emission Trading Scheme (EU ETS) is the largest GHGs emissions trading scheme in the world. It began operation in January 2005.

2.4.2. Limit values for emission of CH_4 from mobil sources.

Directive 1999/96/EC established limit values for CH_4 emission from gas engine together with limits for non-methane hydrocarbons. It is amendment of Directive 88/77/EEC concerning heavy duty vehicles.

Table 24 Limit values for emissions of CH_4 since 1999 due to Directive 1999/96/EC for heavy duty vehicles.

Type of test	Directive 1999/96/EC and 2005/55/EC			
	Euro III	Euro IV	Euro V	EEV (environmentally friendly vehicle)
	2000/ 2001	2005/ 2006	2008/ 2009	
Test ETC (European Transient Cycle) - for gas engines	**g CH_4/kWh**			
	1.60	1.10	1.10	0.65

2.5. Legislation concerning ozone in ambient air.

2.5.1. Concentration of O_3 in ambient air.

Directive 92/72/EC established thresholds for ozone concentration in the air for implementation since March 1994 – see below.

Table 25. Thresholds for ozone concentration in the air due to Directive 92/72/EC.

Parameter		Value
Health protection threshold	mean over 8 hours	110 µg/m^3
Vegetation protection thresholds	mean over 1 hour	200 µg/m^3
	mean over 24 hours	65 µg/m^3
Population information threshold	mean over 1 hour	180 µg/m^3
Population warning threshold		360 µg/m^3

Directive 2002/3/EC (III Daughter Directive for Air Quality Framework Directive 96/62/EC) established new target values, long-term objectives, information and alert thresholds for ozone – see table 26. New thresholds (information and alert) are valid from 2003, target values – from 2010.

Table 26 Values of parameters for ozone in ambient air due to Directive 2002/3/EC.

Parameter		Value	Date by which value is to be met
Target value for the protection of human health	Maximum daily 8-hour mean	120 µg/m^3, not to be exceeded on more than 25 days per calendar year averaged over three years	1 January 2010
Long-term objective for the protection of human health		120 µg/m^3	year 2020 as a benchmark
Information threshold (to protect sensitive sections of the population)	1 hour average	180 µg/m^3	9 September 2003
Alert threshold (for the protection of the general population)		240 µg/m^3	
Target value for the protection of vegetation	AOT40 ([1]), calculated from 1h values from May to July	18 000 µg/m^3·h, averaged over five years	1 January 2010

Long-term objective for the protection of vegetation		6 000 $\mu g/m^3 \cdot h$	year 2020 as a benchmark

([1]) the sum of the difference between hourly concentrations greater than 80 $\mu g/m^3$ (= 40 parts per billion) and 80$\mu g/m^3$ over a given period using only the 1 hour values measured between 8:00 and 20:00. Central European Time each day

2.6. Legislation concerning sulphur compounds.

2.6.1. National emission ceilings for sulphur emission.

Several LRTAP protocols (the 1985 Helsinki Protocol, the 1994 Oslo Protocol) have been assigned to reduce acid deposition of sulphate. The most recent is the Gothenburg Protocol. Europe's sulphur emissions within 2010 should be cut by at least 63% compared to 1990. The protocol established sulphur national emission ceilings and emission for PEMA (Pollutant emissions management area).

Directive 2001/81/EC and Treaty of Accession from 2003 established SO_2 annual national emissions ceilings for 25 European Union countries.

2.6.2. Ceilings for emission of SO_2 from large combustion plants.

Directive 88/609/EEC laid down in Annex I three phases (years 1993, 1998, 2003) of ceilings and targets for reduction of SO_2 from existing large combustion plants. Directive 2001/80/EC concluded emission ceilings for 15 EU countries. The Treaty of Accession from 2003 added ceilings for 10 new EU countries.

2.6.3. Limit values for emission of SO_2 from stationary sources.

SO_2 emission limit values for new large combustion plants were set in Annexes III-V to Directive 88/609 and its amendments Directive 94/66/EC and Directive 2001/80/EC.

Directive 89/369/EEC established limit values for SO_2 emission from new municipal waste incineration plants, and repeated the ones for existing plants in Directive 89/429/EEC. Directive 94/67/EC established limit value for emission from incineration of hazardous wastes. Directive 2000/76/EC established new air emission limit values (in

Annex V) and special provisions for cement kilns co-incinerating waste and combustion plants (in Annex II).

2.6.4. Reduction of emission of SO_2 from mobil sources.

Directive 75/716/EEC established the first standards for sulphur in liquid fuels. Directives 87/219/EEC, 93/12/EC and 1999/32/EC laid down new standards. Directive 2005/33 laid down standards for marine fuels.

The LRTAP Gothenburg Protocol also applied limit values for sulphur content in petrol and Diesel fuel (in Annex IV to Protocol).

2.6.5. Concentration of SO_2 in ambient air.

Directive 80/779/EEC established the first limit values and guide values for SO_2 and suspended particulates in ambient air (annual and for winter period) first implemented in 1982. Directive 89/427/EEC changed limit values based on measurements by a gravimetric methods. Directive 1999/30/EC established new limit values (mainly valid from 1 January 2005) and alert thresholds.

2.7 Summary of historical emission legislations

The first national emission ceilings were established in 1985 for SO_2 in the LRTAP protocol, in 1988 for NO_x and in 1991 for VOC. A set of ceilings for these gases were established in the LRTAP Gothenburg Protocol in 1999. By Directive 2001/81/EC these ceilings were introduced to European Union legislation. Ceilings for emissions of NO_x and SO_2 from large combustion plants were established in 1988 and repeated in Directive 2001/80/EC. The Council Decision 2002/358/EC laid down national reduction targets for greenhouse gases in fulfilment with the Kyoto Protocol.

In EU legislation the first emission limit values were established for passenger cars in 1970 for hydrocarbons and CO. In 1975 the sulphur content of liquid fuels was limitied for the first time. In 1977 limit values for motor vehicles were extended to NO_x. In 1988 the first limit values for emissions of NO_x, hydrocarbons and CO from heavy duty vehicles were established. Emissions from mobil sources were changed many times in the

1990s when standards called Euro I, II, III, IV and V were established. Directive 1999/96/EC also established limit values for emission of CH_4 from gas engines.

The first limit values for emissions of NO_x and SO_2 from large combustion plants were established in 1988. Next year it was done for CO and SO_2 for waste incineration plants and in 1994 for incineration of hazardous wastes. Directives 2001/80/EC and 2000/76/EC are recent EU legislations. Directives concerning emissions of VOC from stationary sources were first implemented in 1994.

Limit and guidance values for concentration of gases in ambient air were defined the first time by EU directives for SO_2 in 1980 and for NO_2 in 1985. In 1992 the first standards for ozone were established. Daughter directives to 96/62/EC set new standards to be implemented by 2005 for CO and SO_2 and by 2010 for NO_x and ozone.

3. Scenarios of policy measures

3.1. Drivers

Policy measures directed towards the drivers of environmental pollution could either aim at influencing the volume of activities or by major shifts of the industrial or societal processes. One of such major shifts could be the large scale introduction of low air pollutant emissions energy technology. Large scale introduction of nuclear energy can serve as one example for such a low emission strategy.

Scenario D.1

Coal fired power plants → Nuclear Power Plants

Emissions from coal fired power plants contribute significantly to the emissions in most countries. Coal is usually used in base load power plants. Some countries have decided to use nuclear power for their base load power plants and have installed a significant capacity in nuclear energy. Other countries have not. Since nuclear power plants do virtually not emit any air pollutants, the nuclear option, if used by all countries would have led to a substantial reduction in the emissions of air pollutants in these countries.

Based on the TNO TEAM database for emissions a scenario has been developed to assess to what extent the present air pollution concentrations could have been lower if all developed countries (OECD member countries) would have replaced all of their coal fired power plants by nuclear power plants between 1975 and 1995. This strategy would have decreased the emissions from coal fired power plants to essentially zero. Since it is directed to a drastic change of the enegry industries, this scenario could be regarded as one example of policy measures directed towards the drivers in the DPSIR scheme.

3.2 Pressures

Two major air pollution policy measures, introduced in Europe in the final decades of the twentieth century were aiming at two sources with important contributions to air pollutant emissions: road transport and especially passenger cars and large combustion plants. Both policy measures are directed towards abatement of emissions, mostly by introducing add on technology to existing technologies. They do not change the activity itself, but aim at reducing the pressures caused by them.

Scenarios P.1

Introduction of catalysts

Emissions from road transport are a major contribution to many air pollution problems. Since 1970 the European Union has introduced a series of directives, setting standards for tail pipe emissions from road vehicles, substantially decreasing the emission factors for CO, NOx and NMVOC. These measures were aimed at reducing the air pollution caused by the ever increasing transport volumes.

In response to these and other policy measures cars have been equipped with catalysts in their exhaust systems. A set of two scenarios was developed for this study to

- assess the contribution of the introduction of catalysts to air quality and
- quantify the maximum potential of this measure

Scenario P.1a

No introduction of catalysts at all in the OECD countries

The first question is answered by comparing the RETRO estimated time series of emissions with a scenario that calculates the emission trends that would have occurred if the 1970 passenger car technologies would have been used during the complete time series of 1970 to 2000, e.g. assuming the same increase in passenger-km or ton-km as in the baseline scenario but without technology improvement. This scenario essentially investigates the influence of the increased transportation demand on the environment. It therefore reflects a worst case for road transport.

Scenario P.1b

Full implementation of Euro III emission standards in OECD countries

The second question is tackled by comparison with a scenario, assuming that the complete passenger car fleet in the OECD gradually complied with the EURO3 standards by the year 2000. In addition the even more stringent emissions standards of the EURO4 and 5 are assumed to be implemented in two variants of this scenario.

This scenario shows the maximum contribution the technological improvements on road vehicles could bring to abating the air pollution impacts by road transport. This scenario could therefore be seen as a (technologically) best case scenario for road transport.

4 Emissions

4.1 Method

The methods applied to develop the RETRO emission inventory are described in detail in the deliverables of WP1 and in Pulles et al. (2006). The TEAM model allows for manipulating both the drivers (activities) and the resulting pressures (applying new technologies). This capability of the TEAM model was used to generate the different emission scenarios for this study.

Kommentar [p1]: Need reference here

The scenarios were developed as modifications of the base case scenario as described in the earlier documents. Table 27 provides an overview of the modifications.

Table 27 Overview of the emission scenarios developed within this project

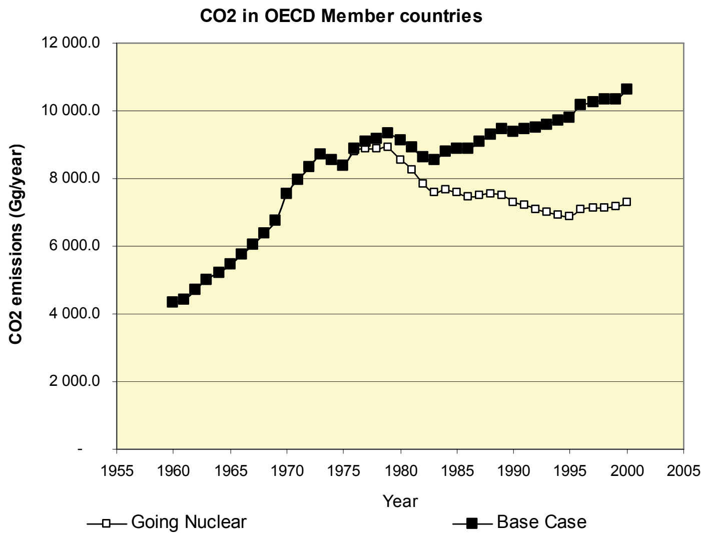
Scenario	**Activity rate adaptations**	**Technology adaptations**	**Technology selection**
D.1 *Going nuclear*	Energy used in coal fired power plants is gradually replaced by nuclear energy between 1975 and 1995. Each year a further 5 % of the fuel used in this source category is replaced by uranium.	The emission factors for all pollutants caused by nuclear energy are set to zero.	For coal still used in power plants, the technology selection is equal to the one in the base case scenario.
P.1a *Road Transport Worst Case*	None	None	The technologies used for road transport of 1970 have been applied for all years since 1970
P.1b *Road Transport Best Case*	None	The Euro III technology was defined with the emission factors equal to the standards set in this document. Variants of this scenario are made for Euro 4 and 5	The transition to a newer technology between 1990 and 2000 is modified to a transition towards a technology fully complying with the Euro III standards in all OECD countries.

4.2 Resulting emissions

4.2.1 D.1: Introduction of Nuclear

The introduction of nuclear energy in the power production is expected to have a significant impact on emissions of carbon dioxide (not included in this study) and on NOx. Since the power plants are relatively small contributors to the emissions of CO and NMVOC, the latter pollutants will not significantly be influenced by this scenario.

Figure 2 presents a time series of calculated emissions of CO_2 and NOx in the scenario and compares these with the base case emissions. It is clearly shown that the emissions of both pollutants are significantly decreased by the assumed large scale introduction of nuclear power plants in the OECD countries. CO_2 emissions from fuel combustion would by 2000 be reduced to the levels of the early 1970s and NOx emissions would be even further reduced, back to the levels that occurred in 1965.



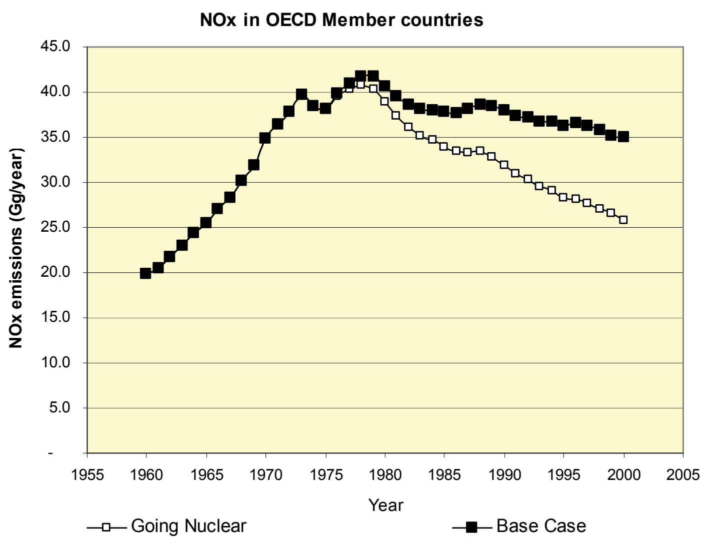
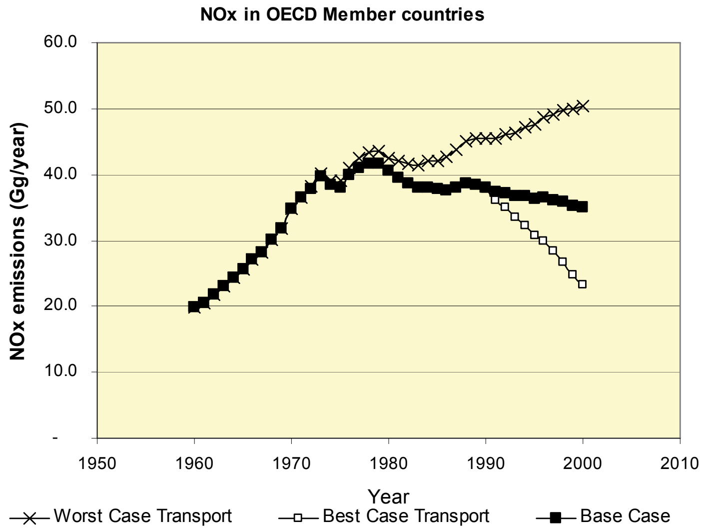


Figure 2 **Comparison of Nuclear Energy scenario with the base case for the OECD member countries (fuel combustion only).**

4.2.2 P.1 Road Transport

The main pollutants affected by the introduction of catalysts are CO, NOx and NMVOC. Figure 3 presents a comparison of the time series of emissions for the two road transport scenarios and the base case.

Kommentar [p2]: Good if TNO also can add CO figure here



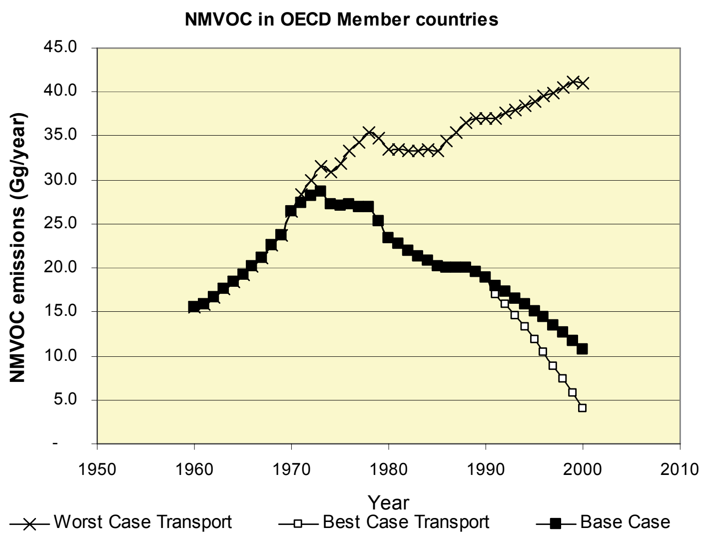


Figure 3 Comparison of Road Transport scenarios with the base case for the OECD member countries (fuel combustion only). **The best case reflects the EURO5 variant of the scenario**

Kommentar [p3]: TNO must confirm

5 Effects on environmental state

5.1 Setup of model studies and analysis

The global chemistry models which performed this study were the two Chemistry Transport models (CTMs) TM4 and OsloCTM2 (CTM2) and the General Circulation Models (GCMs) LMDZ-INCA (LMDZ) and MOZECH (MOZ). Except for TM4 which used operational data, the meteorological data used in the models were based on the ERA-40 meteorological reanalysis. For the GCMs LMDZ and MOZ the meteorological fields are nudged on ERA40 data. CTM2 used six hour forecast meteorology. The models performed a baseline simulation with year 2000 meteorolgy and emissions from the RETRO emission database. LMDZ and MOZ used an updated version of biomass burning emissions which were not included in the simulations performed by CTM2 and TM4. This difference should however have little impact in this study where we focus on relative impacts of various emission scenarios on Europe. In addition to the baseline simulation three scenario runs (Scenario D.1, P1.a, and P.1b described in section 3) were made and results were analysed in sensitivity studies called GOINGNUCLEAR, NOCATALYST and EURO5. MOZ also performed studies called EURO3 and EURO4 based on the variant scenarios under P1.b. In Scenario D.1 described in section 3 all emissions were kept similar to the year-2000 baseline case except year-2000 emissions from power plants in OECD countries for which a shift from coal to nuclear based technology were assumed. GOINGNUCLEAR quantify the impact on the environmental state of this potential technology shift by analysing the differences between the baseline and Scenario D.1 results. The emissions in Scenario P1.a differ from the baseline by the assumption that no catalysts for road vehicles within OECD were introduced. The comparison made in NOCATALYST could therefore reveal to what extent the introduction of catalysts has lead to environmental improvement. As a best case study to quantify the potential for further reductions in road traffic emissions we assumed that the complete OECD passenger car fleet in year 2000 comply with EURO5 standards. The emission datasets used in this study equals the Scenario P.1b described in detail in section

3. MOZ also did simulations with the less stringent EURO3 and EURO4 emission standards.

5.2 Analysis method

In the analysis of the results we discuss seasonal means for wintertime (average over the months January, February and March) and summertime (average over the months July, August and September). These seasonal averages are based on monthly averaged output data from the models. We show results for CO and NO_x in the boundary layer (950hPa). These components are harmful pollutants at high concentrations and precursors of ozone. Ozone is an important photochemical pollutant in Europe and our main focus in this study. Based on AOT_{40} the threshold for crops and semi-natural vegetation is exceeded over most of Europe except in the north and northwest, while exceedance for forests are confined to European mainland (EMEP 2004b). (New research does however propose a flux based approach providing a more consistent relationship with crop yields than using AOT40 as critical values.) EU thresholds for informing the public of 180 $\mu g/m^3$ maximum hourly ozone were exceeded in one third of the monitoring stations and in 17 out of 27 countries reporting in 2002 (EEA 2002). The ambient air quality standards of 55 ppb 8 hours average are frequently exceeded over large parts of Europe. Approximately half of the urban European populations is exposed to concentrations above the threshold value more than 15 days of the year. Based on dose-response relations Stedman (2003) estimated that 21-38 % of the excess deaths during the 2003 heatwave were caused by ozone and PM10 pollution, each component being about equally important. Fischer et al. (2003) did a similar study for the Netherlands and found similar numbers and that pollution of ozone and PM10 was responsible for 8 % of the deaths in the summer 2003.

Tropospheric ozone is a major oxidant and also the main source of the oxidant hydroxyl, a major cleansing agent initiating oxidation of many harmful pollutants and greenhouse gases. Ozone is also a major greenhouse gas. For the greenhouse effect changes in ozone in the upper troposphere are most important. We therefore, in addition to figures for the boundary layer, show the effects of the secenarios integrated over the tropospheric column. We also show plots of the tropospheric nitrate column as the large perturbations in NO_x emissions in the scenarios will affect nitrate, an important component of acid rain. Due to stronger winds and longer chemical lifetimes of nitrate and ozone outside the boundary layer the effects in the free troposphere over Europe will be substantially influenced by emission perturbations on other continents. We do not perform an analysis of the contribution from emission changes in other regions here as Cross Atlantic transport and transport affecting ozone in Europe and North America is discussed in several papers (Derwent 2004, Creilson et al. 2004, Li et al. 2002, Fiore et al. 2002, Parrish et al. 2004). The major export pathways from Europe are to the Arctic, to northeast Asia, over the Mediterranean and into the Atlantic around the Azores high (Duncan & Bey 2004, Lelieveld et al. 2002, Wild et al. 2004).

5.3 Potential of Nuclear Energy

The largest changes of NO_x in the boundary layer for GOINGNUCLEAR are in central Europe where reductions of 30-40 % are found in the winter and 20 to 25 % in the summer (Figure 4). The largest absolute changes (not shown) of -0.5 to -1.5 ppbv are also found here. The absolute changes are small in other regions and typically less than -0.1 ppbv. However the introduction of more nuclear power plants has substantial relative impact in parts of the U.K. (around 20% decrease in winter and a little less in summer), Spain (-20% winter, -10% summer) and in the east Mediterranean region. For the rest of Europe the decrease in NO_x levels are generally below 12 %.

Ozone often has a highly nonlinear response to concentration changes of precursors (Isaksen et al. 1978, Liu et al. 1987, Lin et al. 1988). The maximum increase at 950 hPa of 1-3 ppb (figure 5) or 2-6 % (figure 6) is found over central Europe. Central Europe has the highest reductions in NO_x due to GOINGNUCLEAR but also has the highest NO_x concentration in the baseline simulation. During wintertime the NO_x concentrations in this region is sufficiently high that a titration effect occurs (Kleinman 1991). Peroxy radicals concentrations become low and ozone production is inefficient. A lowering of the NO_x levels as is the case for GOINGNUCLEAR results in more efficient ozone production and more ozone. The reduction in NO_x leads to a small increase in ozone in wintertime over Northeastern Europe in all models. In the rest of Europe there is a small 0-2 % decrease. The highest ozone concentrations in the European boundary layer are found in the summer months when photochemistry is more active. With regard to critical levels for vegetation and health the ozone perturbations during summer is often of more interest. The perturbations in ozone for GOINGNUCLEAR are however generally quite small. Adjacent to the English Channel signs of nonlinearity and a small ozone increase are also found during summer. The introduction of nuclear technology results in ozone decreases elsewhere with a magnitude of 0-3 ppbv or 0-5 %.

The effect on ozone column in wintertime is small. Ozone changes are typically in the range 0 to ±1%. In the summer the effects are larger and a decrease of 1-3 % can be seen over Europe (figure 7). The decrease over the United States is somewhat larger. GOINGNUCLEAR has a substantial effect on the abundance of nitrate (figure 8) in the troposphere and therefore a potential effect on acid precipitation. Reductions in nitrate column over western Europe are typically -5 to -23 % over Europe in winter and a little less in summer.

The models show in general good agreement on the effects of a shift to nuclear technology. All models show strong non-linearity during wintertime over central Europe when a small increase in ozone is found despite large reductions in NO_x levels. Though the differences between the models are minor, MOZ has the smallest absolute and relative NO_x changes in the most affected areas and therefore perhaps also the smallest changes in nitrate. TM4 has the largest ozone perturbations and the largest change in nitrate. CTM2 is the model with the smallest ozone perturbations in the summer boundary layer.

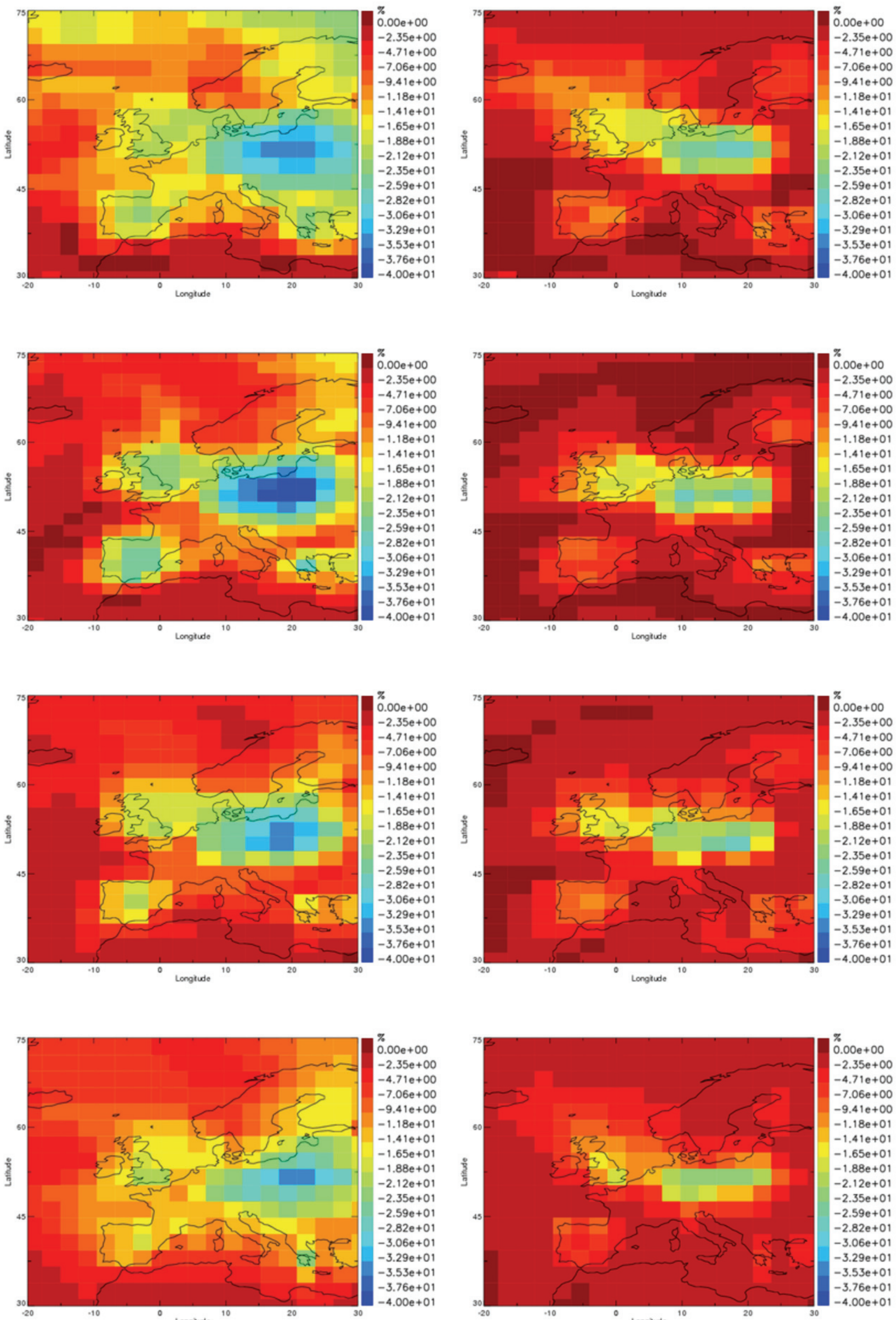


Figure 4. Relative NO_x changes 950hpa GoingNuclear (Jan-Feb_Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

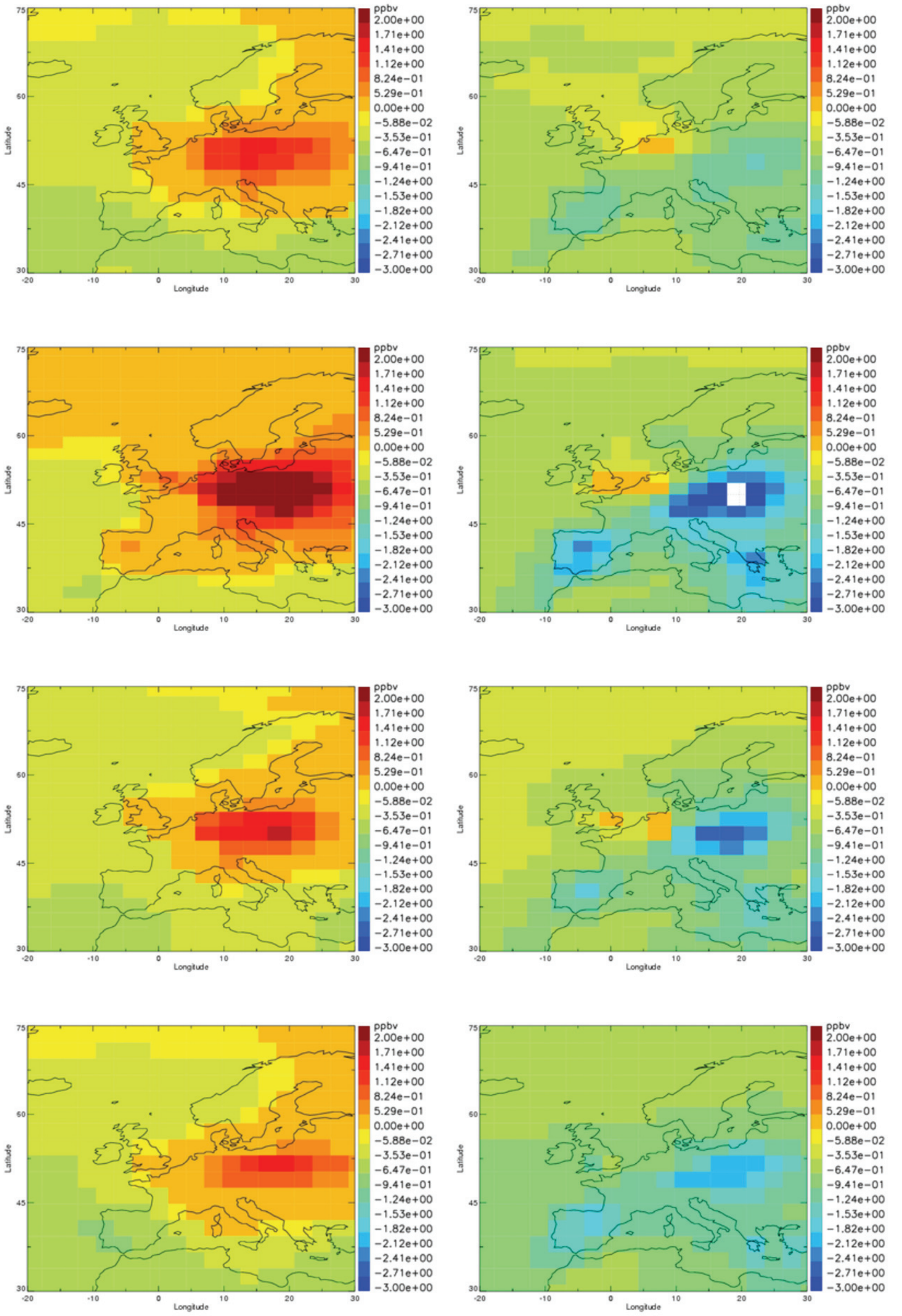


Figure 5. Absolute ozone changes 950hpa Going Nuclear (Jan-Feb_Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

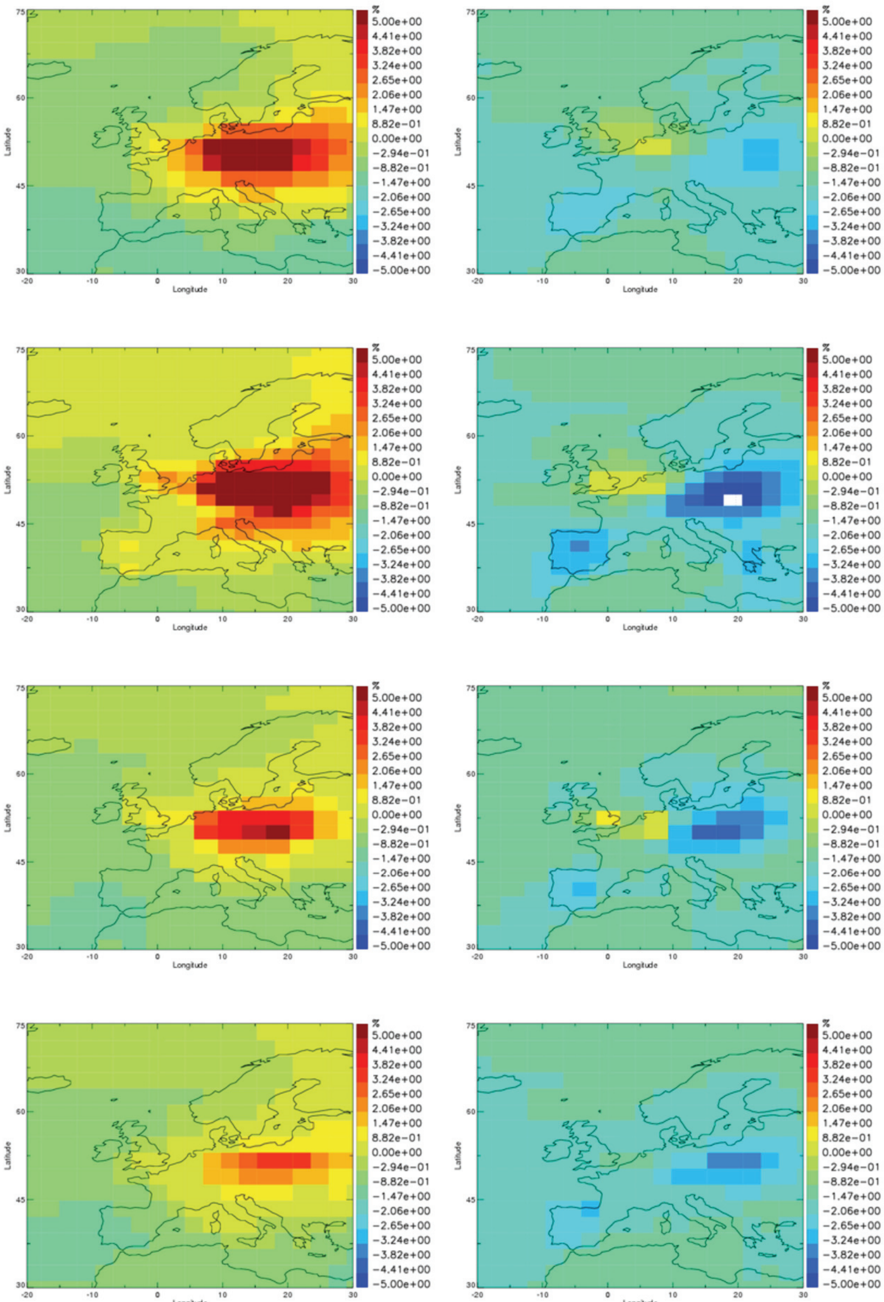


Figure 6: Relative ozone changes 950hpa Going Nuclear (Jan-Feb_Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

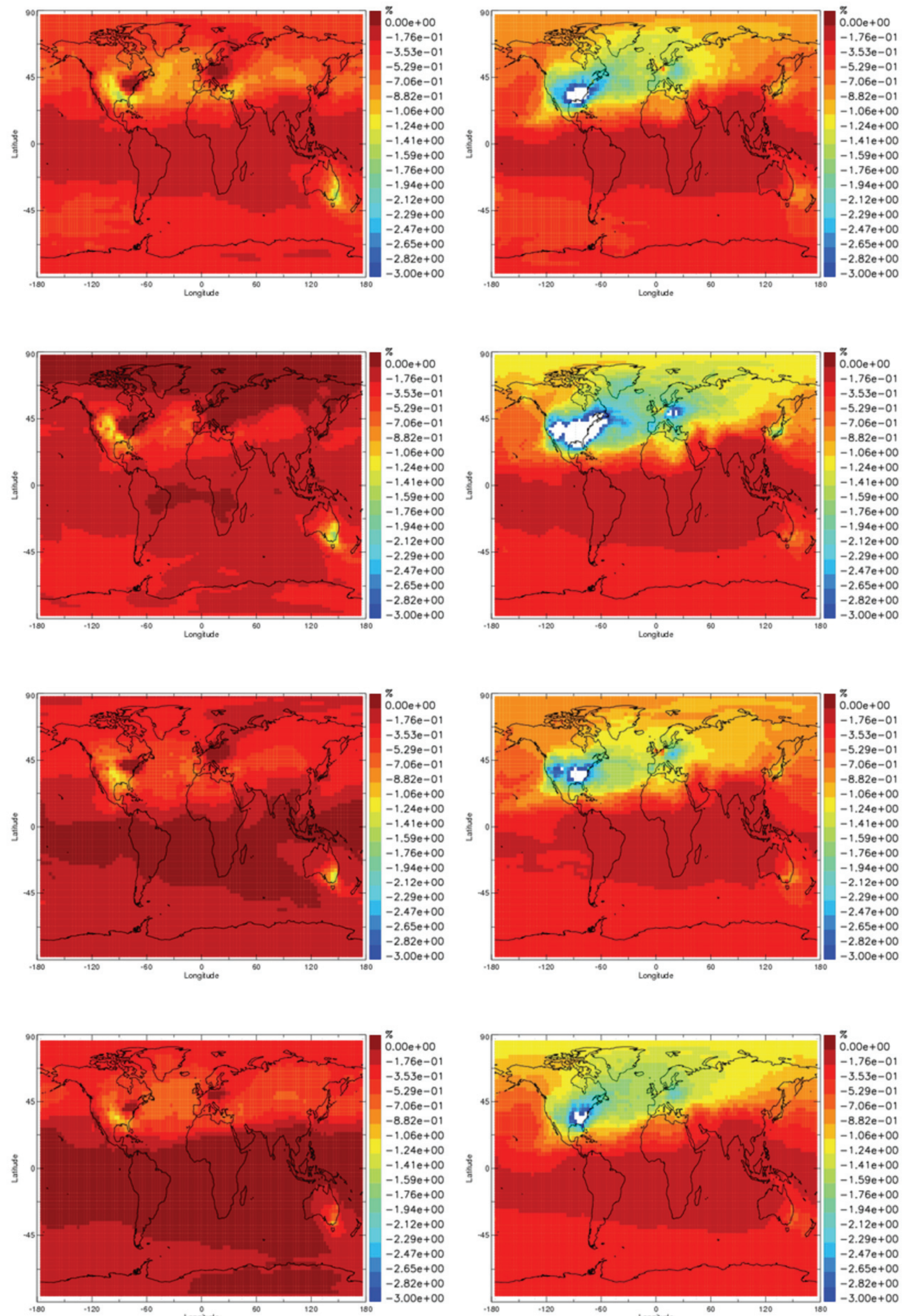


Figure 7. Relative tropospheric ozone column changes Going Nuclear (Jan-Feb_Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

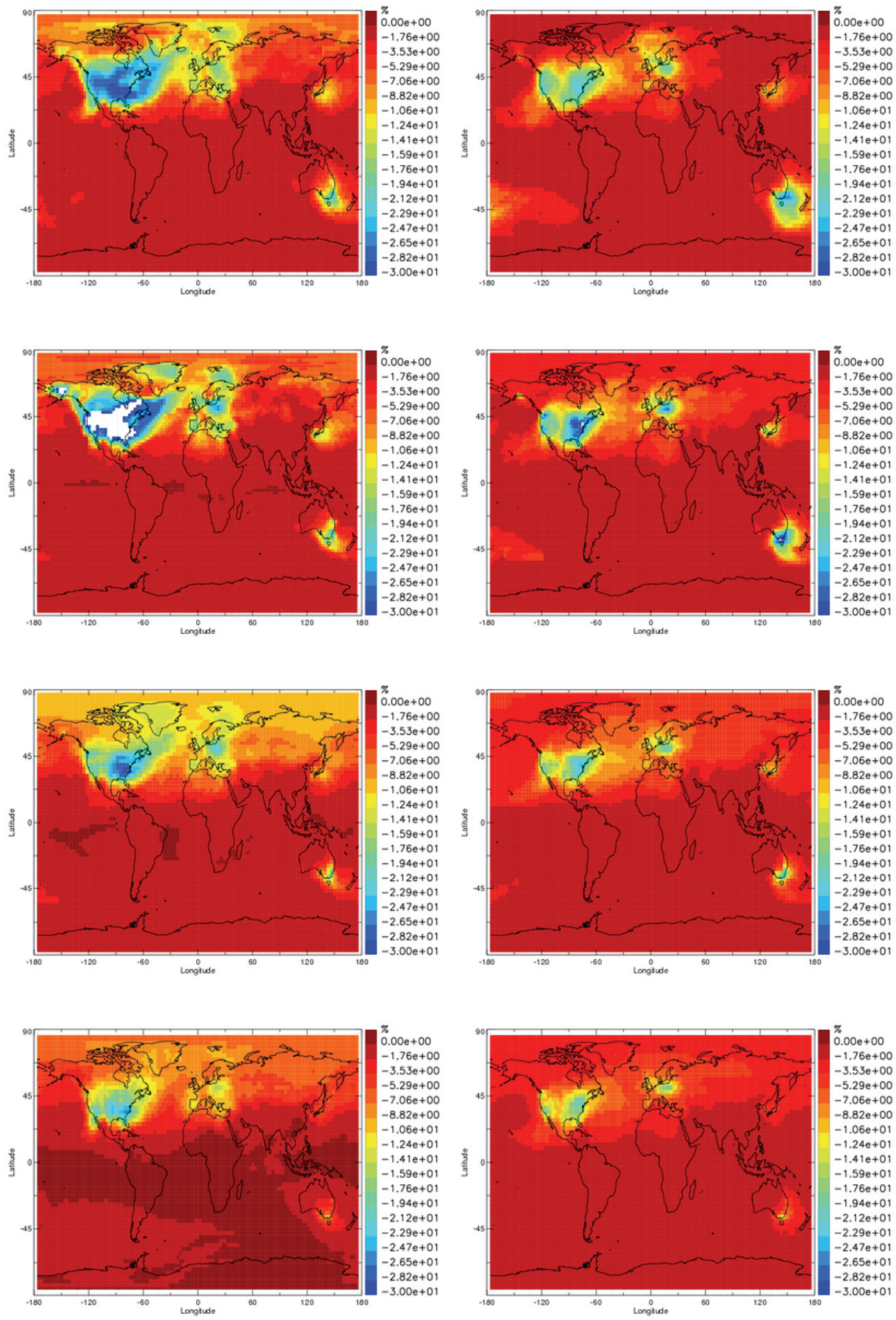


Figure 8. Relative tropospheric HNO_3 column changes Going Nuclear (Jan-Feb_Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

5.4 Road Transport

5.4.1 Effect of introduction of catalysts

In the NOCATLYST analysis in this section we quantify how much higher concentrations of essential pollutants would have been in 2000 if no catalysts were introduced in road vehicles. The absolute increase in boundary layer NO_x (not shown) is highest in all models in wintertime over central Europe, 0-1 ppbv in LMDZ and MOZ and 0-2 ppbv in CTM2 and TM4. Looking at the relative NO_x changes (figure 9) four regional maxima with large increase can be discerned: Central Europe (30-above 40 %), The United Kingdom (30- above 40%), central Scandinavia (20- above 40 %) and Spain (25-30 %). The increases are also large outside these regions.

The catalytic convertors are also efficient in reducing CO and hydrocarbon emissions. The atmospheric concentrations of these components would have been much higher if catalysts were not used. CO concentrations in the boundary layer would have been 40-80 % higher over central Europe and 10-50 % higher in other parts of Europe (figure 10).

The large effect on several ozone precursors (CO, hydrocarbons, NO_x) also leads to large effects on ozone when the photochemical activity is high during summer. Increases of 5-10 ppbv at 950 hPa (figure 11) extend over a large part of Europe corresponding to relative increases of 10-20 % (figure 12). The increases are larger in summer than winter at all places. In winter deficiency of sunlight and nonlinear chemistry at high NO_x concentrations (discussed section 5.3) result in lowest perturbations over northern central Europe (0-2ppbv). The largest increases of 3 to 6 ppbv are found over the Meditteranenan where there is more sunlight available.

Typical column ozone summer increases (figure 13) in the most impacted OECD regions (western Europe, the U.S. and Japan) is 4-12 %. The perturbations are larger and the regions with maximum increase more distinct during the summer season. However the increase during the winter season is also significant.

The increase in nitrate column (figure 14) is substantial and can reach 30-45 % in CTM2 and TM4 and 25-30% in LMDZ and MOZ. In wide regions around the maxima increases in the order 10-15 % can be found.

The spatial patterns of the the modeled perturbations again agree rather well. However, the magnitude of change is quite different for some components. For CO the magnitude of change varies by a factor of 2. It is also evident that CTM2 has a larger absolute increase of boundary layer NO_x during winter while the relative increases are smaller in the TM4 than in the other models. CTM2 has the highest ozone perturbations both for the column and the remote background boundary layer. MOZ shows the smallest changes in ozone and nitrate column.

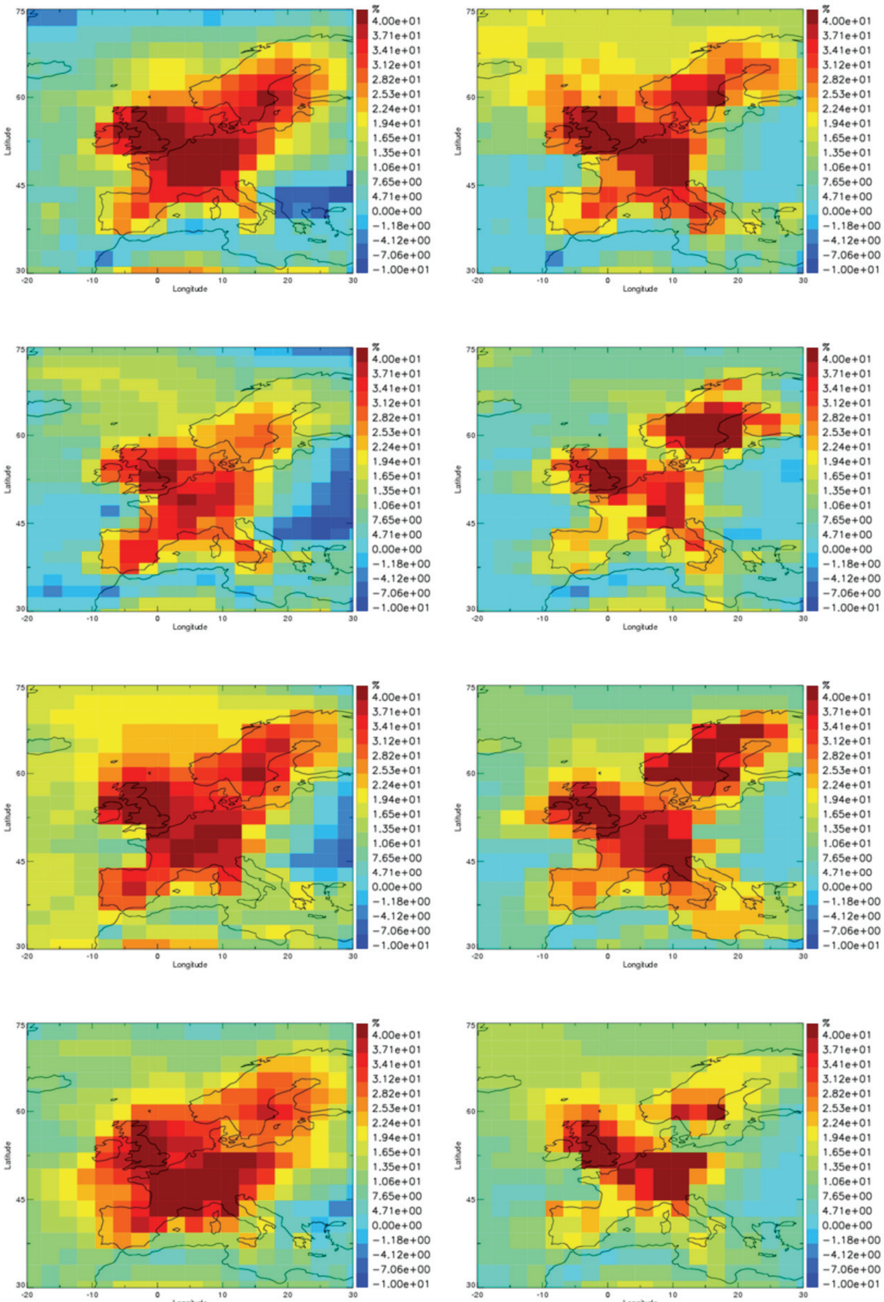


Figure 9. Relative NOx changes 950hpa NOCATALYST (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

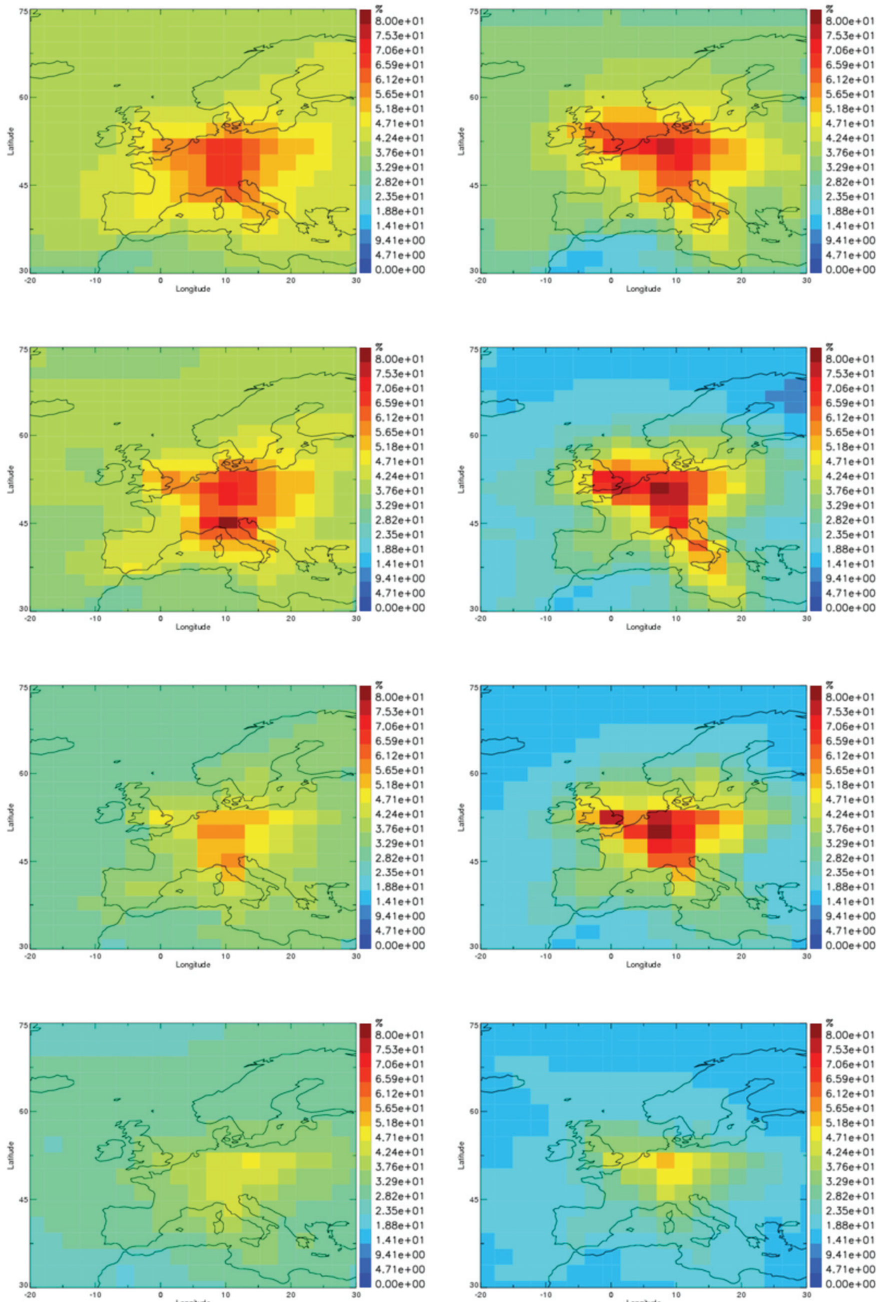


Figure 10. Relative CO changes 950hpa NOCATALYST (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

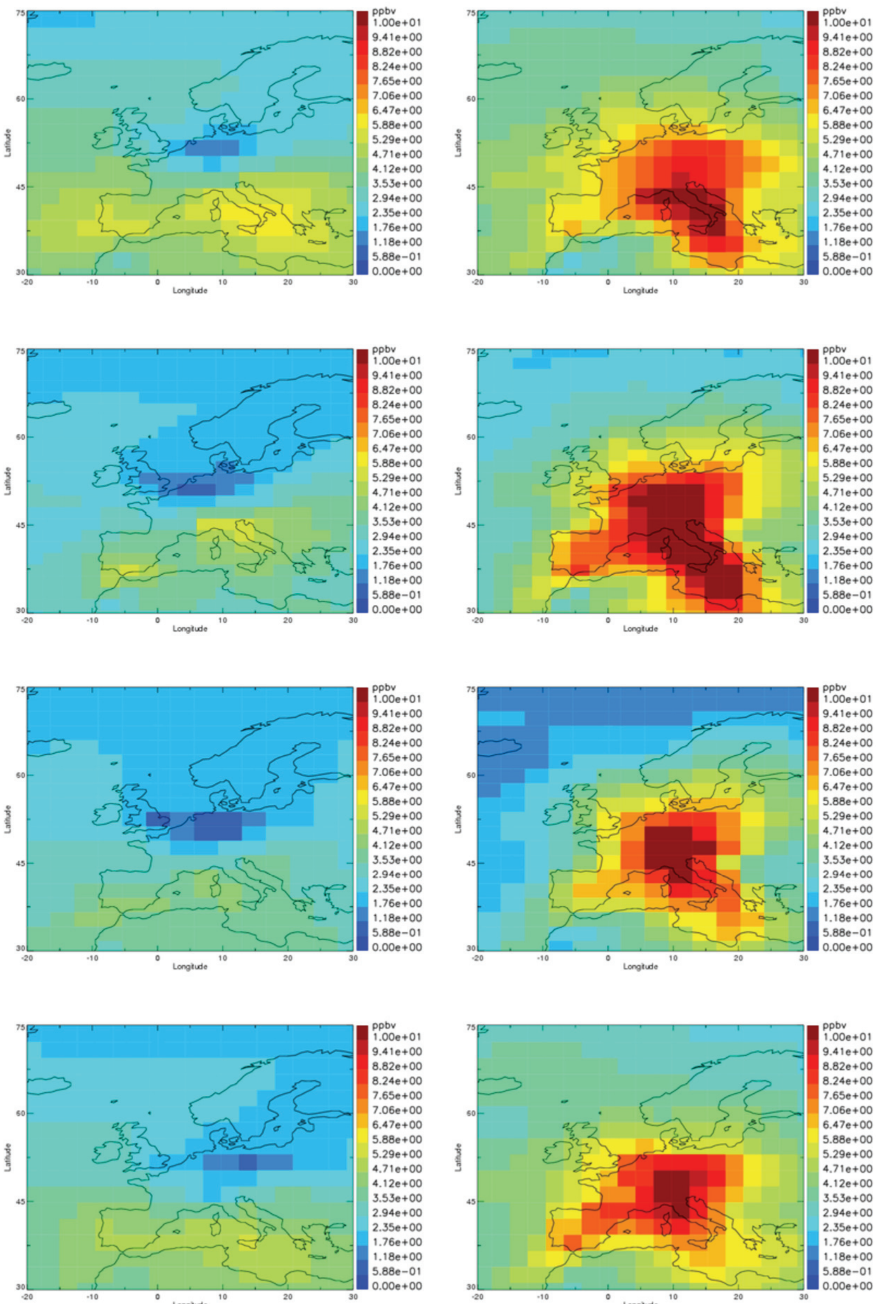


Figure 11. Absolute ozone changes 950hpa NOCATALYST (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

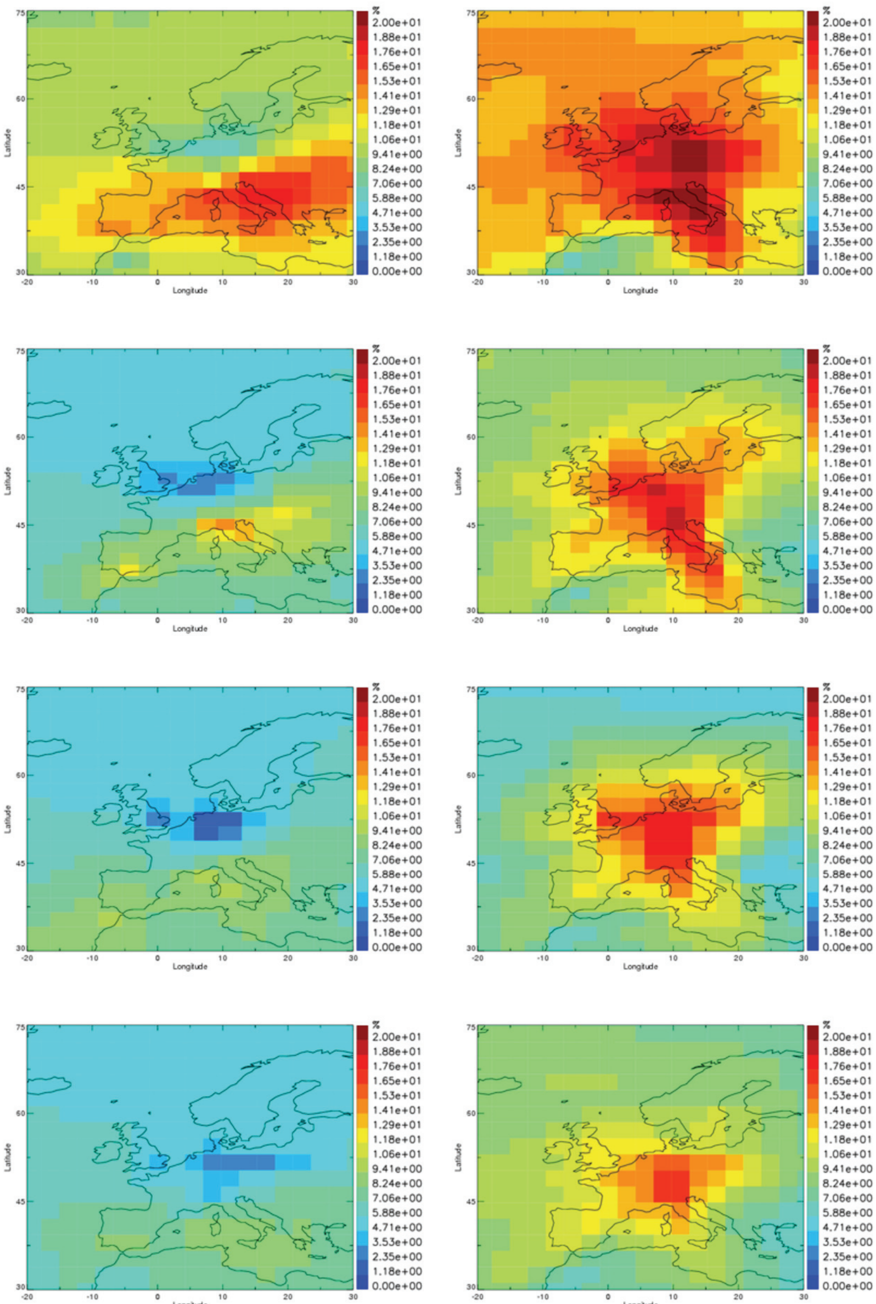


Figure 12. Relative ozone changes 950hpa NOCATALYST (Jan-Feb-Mar mean left column, July-August-Sep mean right (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

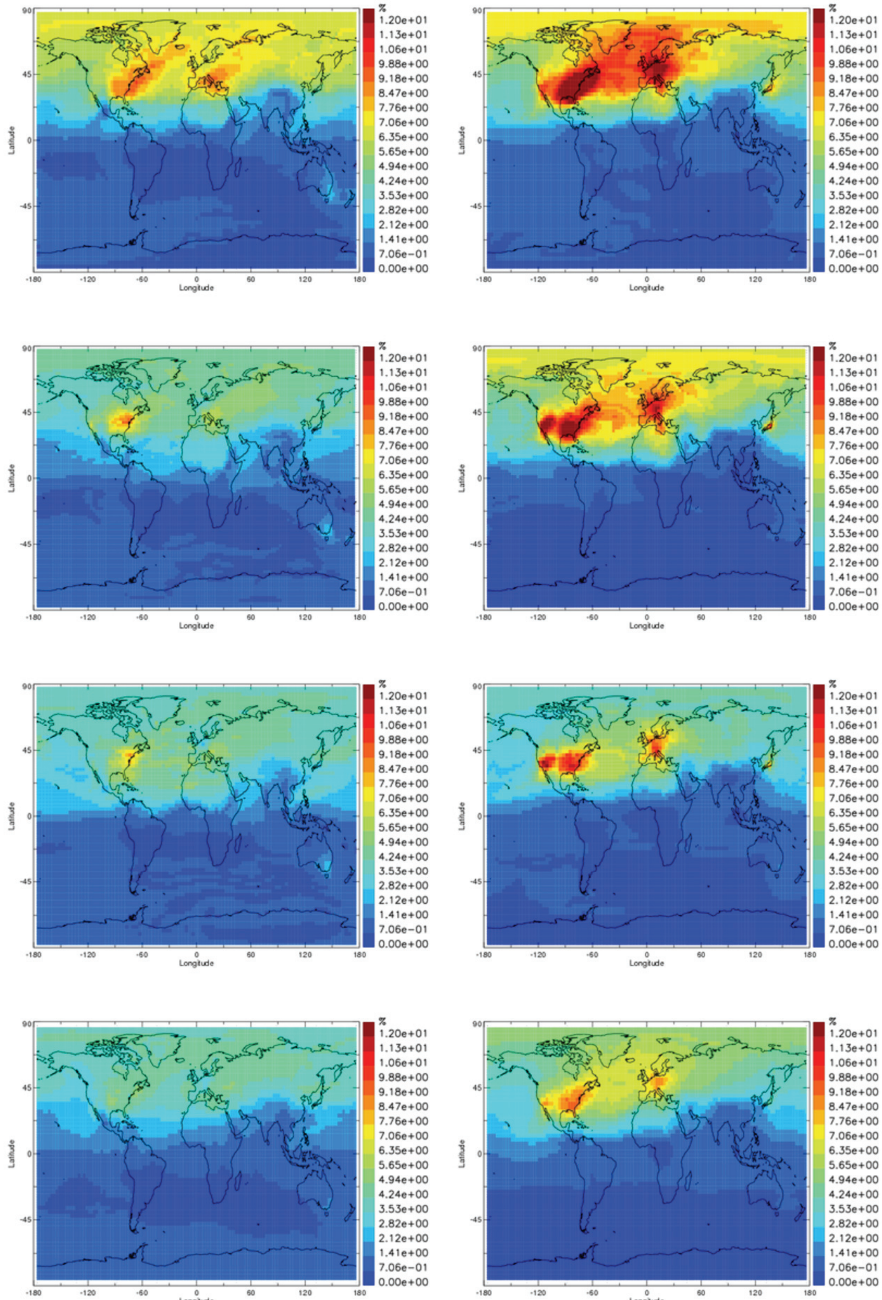


Figure 13. Relative tropospheric ozone column changes NOCATALYST (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2[nd], LMDZ 3[rd], MOZ lower)

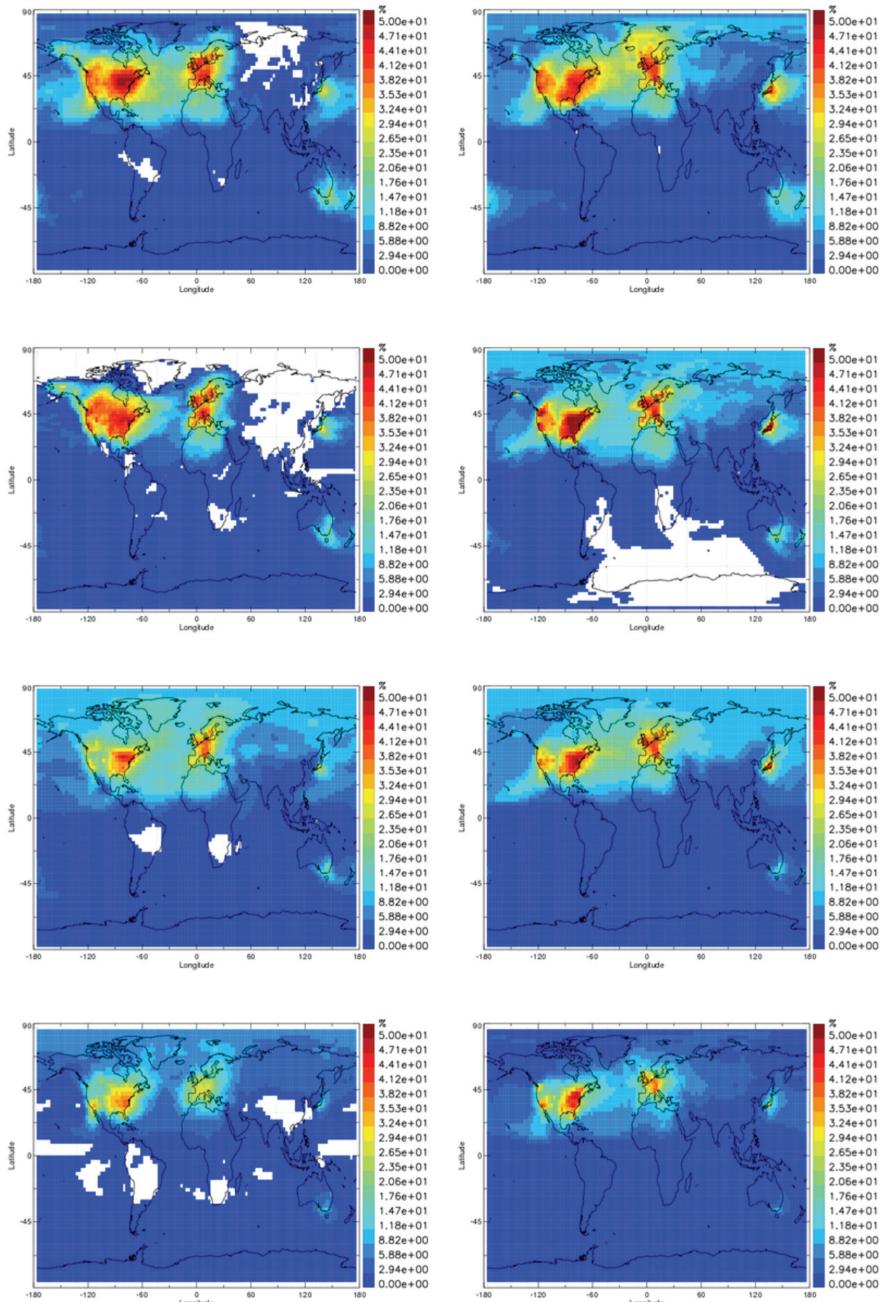


Figure 14. Relative tropospheric HNO_3 column changes NOCATALYST (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

5.4.2 Potential for further reductions (impact of EURO5)

A complete shift to EURO5 technology in all OECD countries would result in a reduction of boundary layer NO_x (figure 15). The reductions are in the range 25-60 % over much of continental western Europe. The absolute reductions (not shown) are 0.5-2 ppbv in winter and 0.5-1 ppbv in summer in central Europe and 0-0.5 ppbv elsewhere.

Changes in CO (0 to minus 3 %, not shown) are small as EURO5 gives small changes in emissions. Much of the potential for achieving CO reductions with current technological knowledge has already been achieved by the introduction of catalysts.

In winter all models show an increase in boundary layer ozone (0-2 ppbv or 0-3%, figure 16 and 17) in central Europe despite a large NO_x decrease. This is likely due to the titration effect discussed in section 5.3. This increasing ozone is opposite to the sign of the ozone change due to the introduction of catalysts even if the NO_x decreases are quite similar. At the high NO_x concentrations found over central Europe ozone production becomes more dependent on the levels of hydrocarbons and CO. As the catalyst results in large reductions in these components whereas the EURO5 does not lead to further reductions, this is likely to explain the difference in ozone response. Outside central Europe the wintertime 950 hPa ozone decreases by 0-2.5 ppbv (0-5 %) due to EURO5. In summer the largest reductions in boundary layer ozone are found in southern Europe and are in the range 4-12 ppbv which is larger than 10 %. The relative reduction is 5-15 % over large parts of western Europe.

The decrease in ozone column (figure 18) is quite homogenous and 0-3 % over the northern hemisphere in wintertime. In summertime the decrease over Europe is significant and reaches 4-8 %.

Large effects are found for the nitrate column (figure 19). The decrease over Europe typically amounts to 15-45 %.

CTM2 has the highest absolute boundary layer wintertime NO_x decrease of the models while MOZ in general has the smallest NO_x changes. TM4 shows the largest effects on boundary layer ozone and nitrate column. In general MOZ shows the smallest perturbations due to EURO5.

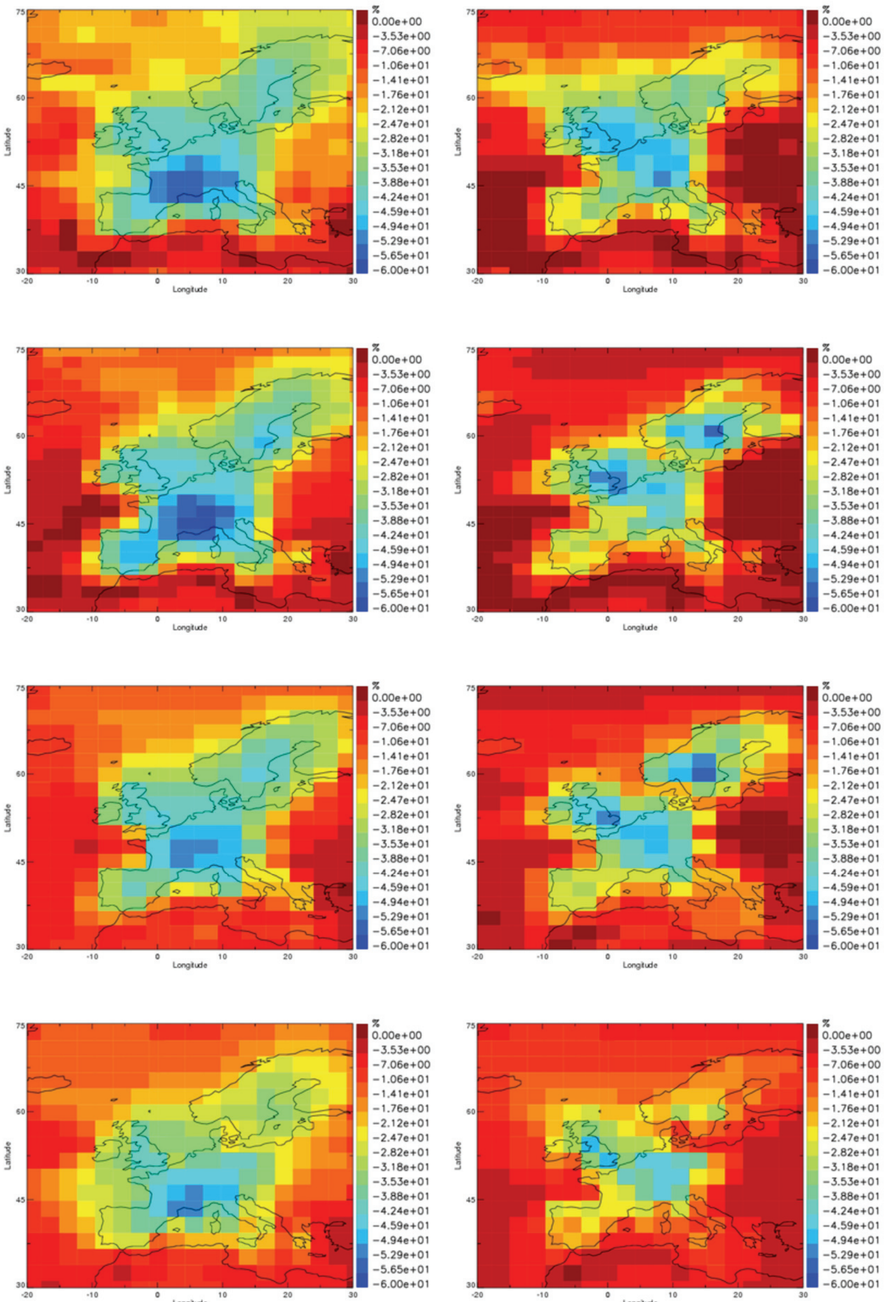


Figure 15. Relative NOx changes 950hpa EURO5 (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

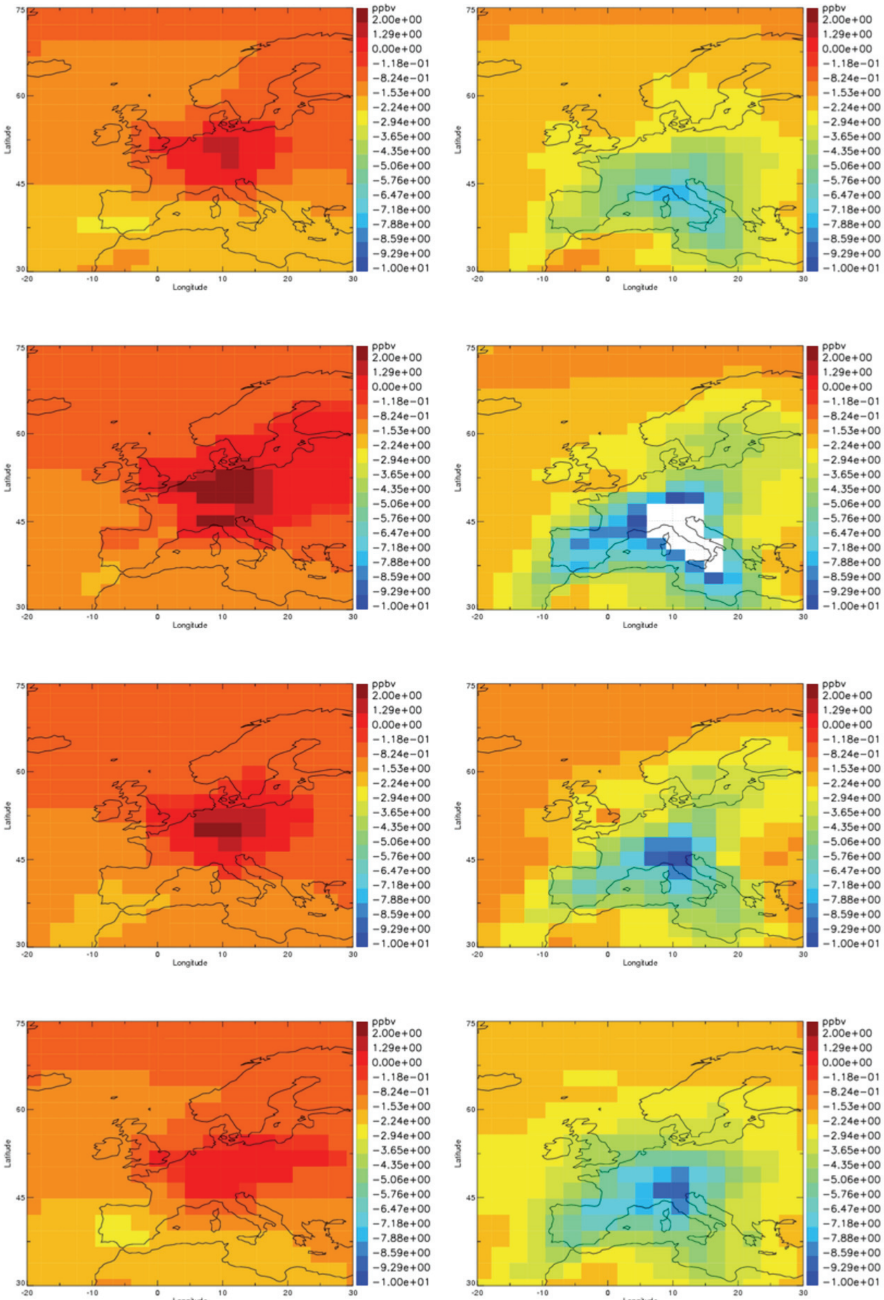


Figure 16. Absolute ozone changes 950hpa EURO5 (Jan-Feb_Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2[nd], LMDZ 3[rd], MOZ lower)

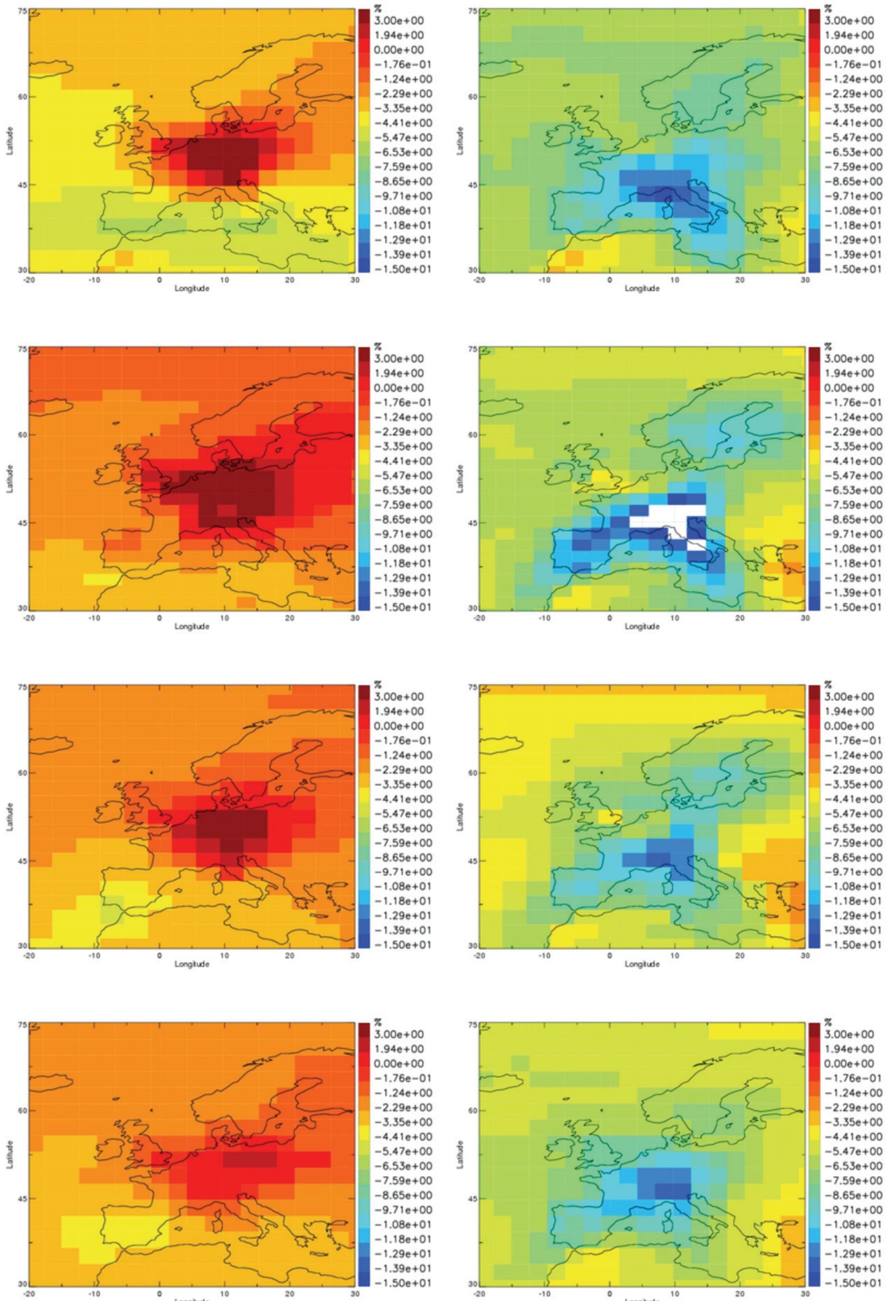


Figure 17. Relative ozone changes 950hpa EURO5 (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

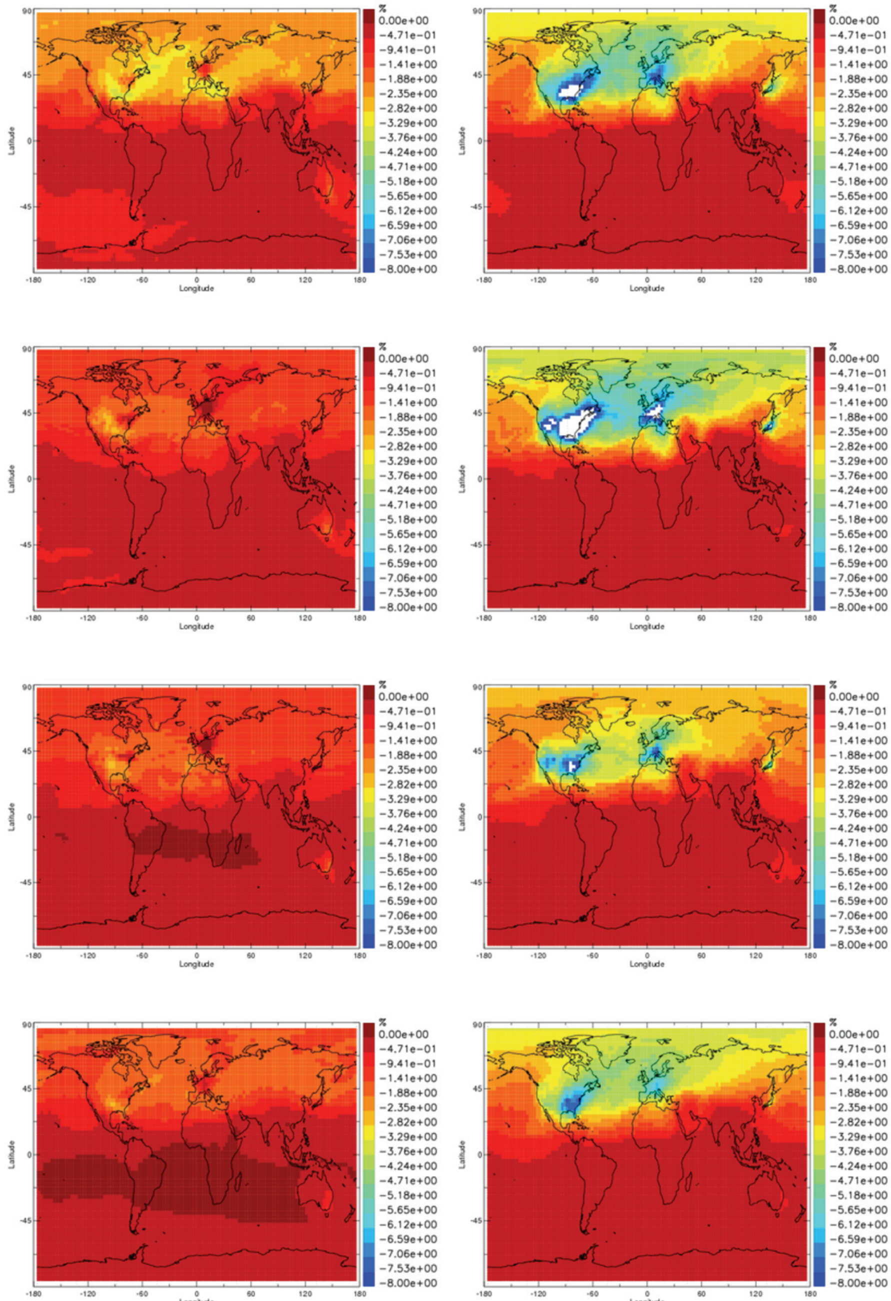


Figure 18. Relative tropospheric ozone column changes EURO5 (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

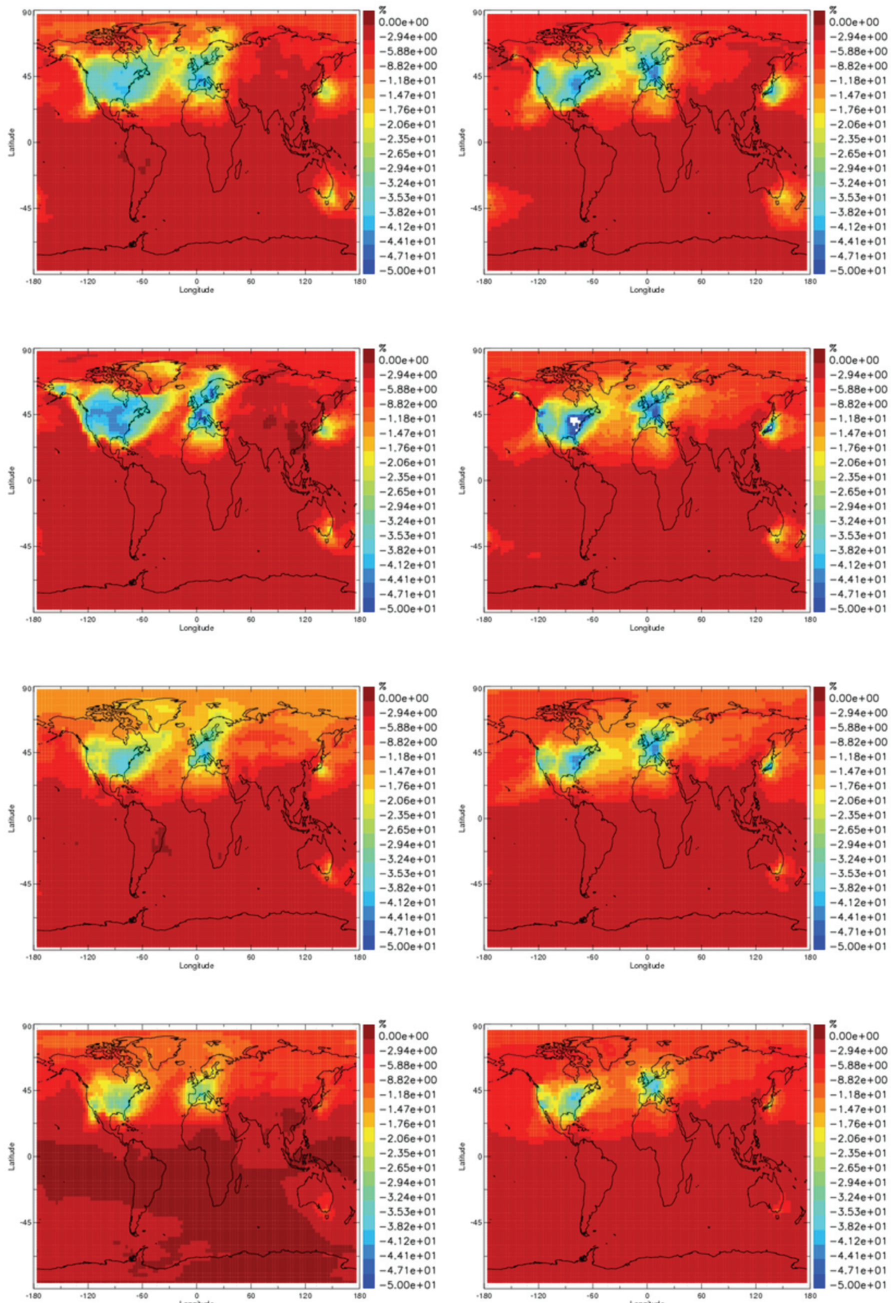


Figure 19. Relative tropospheric HNO_3 column changes EURO5 (Jan-Feb-Mar mean left column, July-August-Sep mean right column) (UiO upper row, TM4 2nd, LMDZ 3rd, MOZ lower)

5.4.3 Comparison of the effects of EURO3, EURO4 and EURO5

MOZ did sensitivity runs in order to compare the effects of newly introduced and planned technological measures (see section 1.2.3 and section 3) for road traffic. The impacts on boundary layer ozone and NO_x of a complete shift in OECD countries to EURO3, EURO4 and EURO5 technology respectively is shown in figure 20. As expected the more stringent EURO5 leads to the highest reductions in pollutant levels. The differences between the measures are significant but not very large. In the most impacted regions EURO5 results in approximately 5-10% larger reduction in NO_x and 0-3 % larger reduction in ozone than for EURO3. MOZ was the model showing the smallest changes due to introduction of EURO5 (section 5.4.2) and as it was the only model to perform this study, its results probably reflect a lower limit of the sensitivity towards the transition from EURO3 to EURO 4 and EURO5 and some caution must be taken in the interpration of the results.

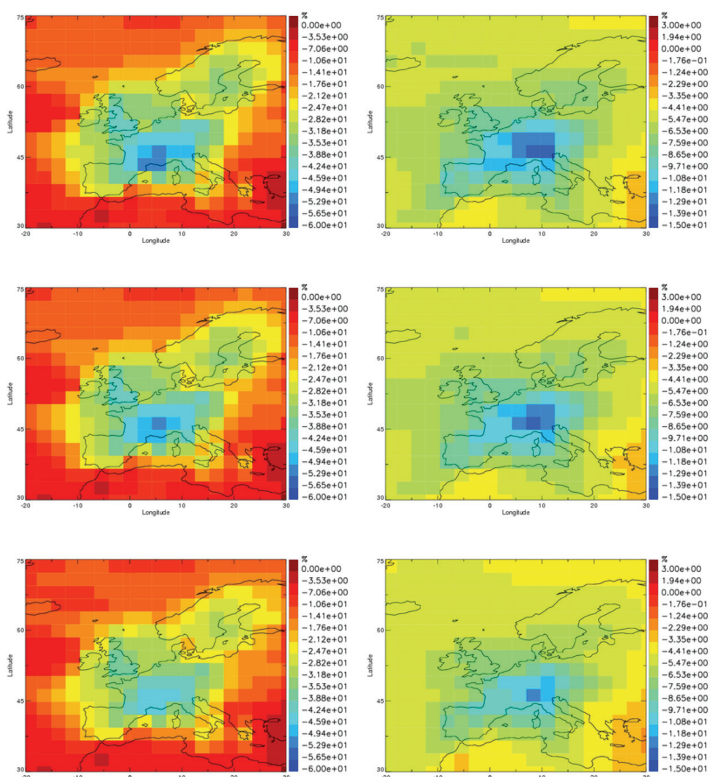


Figure 20. MOZ relative NOx changes(Jan-Feb-Mar mean left column) and ozone changes (July-Aug-Sep mean right column) at 950 hpa (EURO5 upper row, EURO4 middle, EURO3 lower)

5.5 Summary and Conclusions on effects on environmental state

Based on scenarios related to measures for the energy sector and road traffic in OECD countries emission datasets were developed for use in global models. The models taking part in RETRO performed sensitivity studies and the results were used to analyse the effects of the scenarios on the environmental state in Europe. This is one of the first studies where policy relevant scenarios were investigated with several different state-of-the-art models. The agreement between the model results was in general very good for all three sensitivity studies regarding the sign and spatial patterns of perturbations. When it comes to the magnitude of the changes there is good agreement in the sensitivity study for the energy sector while the results are more variable for the road traffic scenarios. The overall outcome of the model comparison gives us some confidence in the calculated results and the conclusions made in the coming paragraphs. We believe that the results give an indication of the effects of policy measures though it should be noted that we did not investigate effects of uncertainties in the emission estimates and their regional distribution.

The model results indicate that a shift to nuclear technology could lead to significant reductions in NO_x levels in heavy polluted regions. The full extent and magnitude of this effect locally and regionally is uncertain as power plants are small point sources and chemistry is nonlinear. This might not be fully resolved by global models due to relatively coarse spatial resolution. The effects on ozone are quite small. This is much related to non-linear chemistry and in wintertime all models in fact shows a small increase in ozone over central and northeastern Europe. In summer the models indicate reductions that might be of some importance with 0-5 % decrease in the European boundary layer and 1-2.5 % for the tropospheric column. The introduction of nuclear technology would result in a large reduction in nitrate, a component which is readily taken up in precipitation and contributes to acid rain.

The introduction of catalysts in road vehicles has had a large impact on the environmetal state leading to significant reductions of several air pollutants. If it had not been for catalysts boundary layer concentrations of CO and NO_x over much of Europe would have been 10-80 % higher. The large change in ozone precursors also results in improvement of ozone levels especially during summer when the problem is most critical. Without catalysts boundary layer ozone would have been 5-10 ppbv or 10-20 % higher over a large part of Europe. Catalytic convertors also have a smaller but significant effect on tropospheric ozone column and have therefore possibly to some extent reduced the climate forcing of this greenhouse gas. The reduction in nitrate column due to this technological measure is substantial and up to 30-40 %.

The potential of further reductions in road traffic related pollutant levels was analysed from a sensitivity study with EURO5 regulations. EURO5 leads to large reductions in NO_x, especially in regions with high NO_x levels. The reductions in CO and hydrocarbons are smaller than those achieved by the introduction of catalysts and this result in somewhat lower effects on boundry layer ozone, at least in regions with high NO_x levels. On the other hand the ozone reductions are significant and particulary large (above 10 %) in southern Europe a region suffering from episodes with high surface ozone during summertime. In summertime the decrease in tropospheric ozone column over Europe is also significant and reaches 4-8 %. Large effects are also found for the tropospheric nitrate column. Decreases over Europe typically amount to 15-45 %.

One model performed sensitivity studies on effects of newly introduced and planned technological measures to reduce emissions from road traffic. The most restrictive EURO5 leads to the largest reductions of pollutant levels in the European boundary layer compared to the baseline year 2000 simulation. EURO3 and EURO4 also result in large decreases and the differences compared to EURO5 are noticeable but not large. The differences seem to be larger between EURO3 and EURO4 than between EURO4 and EURO5.

Tables 28 and 29 are made for easy comparison of the simulated effects in the sensitivity studies. We have chosen to highlight the effects on NO_x in wintertime and ozone in summertime in the boundary layer over western central Europe. At these times of the year these pollutants may reach high concentrations and have severe environmental impacts as noted in section 5.2. For instance over the area defined in tables 28 and 29 all models have average summer ozone above 40 ppbv which is regarded as a threshold level for damage to vegetation. The differences between the models and the results on smaller scales (maximum, minimum changes) are discussed in the previous sections, here we focus on a larger regional average of the four models. All the scenarios seem to result in a large reduction in wintertime NO_x in the boundary layer over western central Europe. In average the four models calculate that a shift from coal to nuclear technology in power plants could reduce NO_x concentrations with about 20 %. Without the introduction of catalysts for road traffic the NO_x levels would likely have been more than 30% higher. A full shift to EURO5 technology could lead to a further reduction of about 35 %. For ozone the average changes are quite small for a shift to nuclear technology. The introduction of catalyst has significantly reduced boundary layer summer ozone (without catalysts average ozone would have been 14.3 % higher) due to concurrent changes in several ozone precursors (NMVOCs, CO and NO_x). EURO5 could lead to substantial reductions in ozone (almost 10 % in the central western European summer boundary layer). However, in the model calculations EURO5 is not as efficient in reducing ozone as the introduction of catalysts. This is probably due to the previously mentioned fact that EURO5 mainly reduces NO_x emissions and is less efficient in reducing the emissions of other ozone precursors.

Table 28: Relative wintertime (Jan-Feb-Mar mean) NO_x changes (%) at 950 hpa over central western Europe (37.5º-55ºN, -10º-25º E covering ar region from southwest Portugal to eastern Greece and from northwest Great Britan to the Baltics) for the different scenario simulations.

Sensitivity study/Model	Average concentration (ppbv)	GOINGNUCLEAR	NOCATALYST	EURO3	EURO4	EURO5
UiO	3.69	-24.9	38.5			-37.1
TM4	1.61	-21.1	24.9			-35.4
LMZ	1.19	-17.6	29.4			-33.6
MOZ	1.85	-22.7	40.5	-31.4	-33.5	-34.6
Average	**2.09**	**-21.6**	**33.3**			**-35.2**

Table 29: Relative summertime (Jul-Aug-Sep mean) ozone changes (%) at 950 hpa over central western Europe (37.5º-55ºN, -10º-25º E covering ar region from southwest Portugal to eastern Greece and from northwest Great Britan to the Baltics) for the different scenario simulations.

Sensitivity study/Model	Average concentration (ppbv)	GOINGNUCLEAR	NOCATALYST	EURO3	EURO4	EURO5
UiO	45.0	-1.5	17.5			-9.7
TM4	62.4	-2.2	14.6			-10.7
LMZ	57.8	-1.9	13.0			-8.2
MOZ	63.5	-1.8	12.1	-7.1	-7.9	-8.1
Average	**57.2**	**-1.9**	**14.3**			**-9.2**

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