CASE STUDY 1

COMPARISON OF THE EU AND US APPROACHES TOWARDS ACIDIFICATION, EUTROPHICATION AND GROUND LEVEL OZONE

4 October 2004

Annex I:	**Particle characterisation and health effects of acidification, eutrophication and ground level ozone**
Annex II:	**The EU approach towards acidification, eutrophication and ground level ozone**
Annex III:	**The US approach towards acidification, eutrophication and ground level ozone**
Annex IV:	**The Canadian approach towards acidification, eutrophication and ground level ozone**
Annex V:	**The Japanese approach towards acidification, eutrophication and ground level ozone**

1. INTRODUCTORY OVERVIEW

This case study compares the EU and US approaches to the regional air quality problems of acidification, eutrophication and ground-level ozone. Acidifying and eutrophying pollutants originate primarily from anthropogenic emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3). Most of SO_2 and NO_x are emitted to the atmosphere from combustion of fossil fuel in power plants, industrial plants, residential heating, commercial and service sectors. Road transport, shipping and aircraft are significant sources of NO_x emissions. NH_3 emissions are related to agricultural activities.

Ground-level ozone is formed when NO_x and VOCs are subject to photochemical activity. Emissions of VOC are emitted from combustion and also by evaporation of fuels and solvents from stationary sources as well as traffic. Natural emissions, in particular hydrocarbon from vegetation, also contribute to the photochemical activity. Ground level ozone in both Europe and North America affects human health and leaf injury in plants, and causes damages on materials – particularly organic materials. Episodes with high levels of ozone occur mainly during the summer, and especially in the southern parts of Europe and the eastern and western portions of the US and where the emissions of precursors are high.

The above pollutants contribute to the formation of secondary particles (PM_{10}/$PM_{2.5}$), and human health effects. Descriptions of the chemical processes and the effects are given in Annex 1.

2. COMPARISON OF THE TWO APPROACHES

To fully understand and compare the achievements in these various jurisdictions it is important to understand the general philosophy behind acidification, eutrophication, and ozone regulation. The legislation adopted and implemented in these two regions and in Canada and Japan is discussed in greater detail in the case studies (annexes 2, 3, 4 and 5) and in the database.

2.1. Acidification and Eutrophication in the EU

Efforts to address acidification and eutrophication include emissions reductions for SO_2, NO_x, and NH_3. The regulations to control acidifying and eutrophying pollutants in Europe are aimed at addressing the combined effects of SO_2, NO_x and NH_3. This is because in Europe emissions from traffic as well as from agriculture - in addition to stationary sources -contribute significantly to acidification and eutrophication. This is in contrast to the US, where focus is on SO_2 from stationary sources. The emissions of these pollutants are also involved in the formation of particles (secondary particles), which makes the transport over long distances possible, and also influence the PM pollution implicated in human health problems (see case study 4, on particulate matter). NH_3 is mainly an environmental problem in the Northern and Central parts of Europe. The reductions of NH_3 emissions have until now been rather limited.

Controls on long-range transport. Since acidifying, eutrophying, and ozone forming air pollutants - gases and particles – can be transported over long distances, e.g. thousands of kilometres, across national/state boundaries and cause damaging effects far away, the EU has addressed these impacts by setting in place controls over emissions that cut across all Member State jurisdictions. Nonetheless, parts of Europe are separated to some extent in relation to these air pollution problems, e.g. Scandinavia and the Mediterranean countries, and this factor has led to regional differentiation of emissions reduction targets for certain pollutants.

In Europe, these emissions reduction targets and measures have evolved via discussion, collaboration, and commitment among the different countries in the context of the UNECE Convention of Long-

Range Transport of Air Pollution (CLRTAP). A series of CLRTAP Protocols on emissions reductions were agreed among various European countries, starting with SO_2 in the early 1980s and expanded to include NO_x, VOCs, PM and NH_3. Within the EU, Directives were developed for regulation of stationary and mobile sources, *inter alia* in support of the Protocols. The recent Gothenburg Protocol was implemented for the EU countries by the NEC Directive, which sets more stringent national emissions ceilings than were agreed under the Protocol.

Use of command-and-controls approaches, with some application of emissions trading in specific countries. In the EU, regulation has been largely based on so-called “command and control”, and still seems mainly to be so. A very important element in the EU legislation is the Large Combustion Plant Directive which sets emission limit values for SO_2, NO_x and dust. First adopted in 1988, it was updated in 2001 with more stringent ELVs, in parallel with the adoption of mandatory national emissions ceilings for SO_2, NO_x, VOCs and NH_3 via the NEC Directive. The IPPC Directive which requires best available techniques for pollution control at major industrial installations is another important measure that includes large livestock rearing operations, and thus also addresses NH_3.

In addition, a few European countries have applied economic instruments in this area. For example, the Netherlands has initiated emissions trading for NO_x. Several other countries, e.g. Sweden, Denmark, France, and the Netherlands, have applied emission taxes and charges to special sectors and for specific pollutants such as SO_2 and NO_x emissions.

In the early years of EU standard setting in the area of air quality, bureaucrats have generally convened in more or less closed sessions to advise and take decisions. However, in the past decade, individual scientists, the World Health Organisation, NGOs and the industry have been much more involved in the work of developing standards and measures at EU as well as national levels. .

SO_2, NOx, NH_3 reduction targets set for each country. Protocols under the CLRTAP aimed at reducing emissions of SO_2, NO_x and NH_3 were based on the critical loads[1] concept. This concept was used for negotiations in Europe of emissions reductions in the individual countries based on integrated assessment modelling (RAINS[2]). The aim was to protect the major part of the sensitive ecosystems against acidification and eutrophication. In practice, the recent agreement (the Gothenburg Protocol and NEC Directive) aimed at a 50% reduction of the area of unprotected ecosystems, compared to the situation in 1990.

2.2. Acidification and Eutrophication in the US

Efforts to address acidification primarily focused on SO_2, with other requirements for NO_x reductions. The scientific understanding in the US during the late 1980s suggested that SO_2 was the largest contributor to acid rain and the electricity sector was estimated to account for two-thirds of the SO_2 emissions, so the program was primarily aimed at SO_2 emissions from these sources. Therefore, primary effort, through Title IV of the 1990 CAAA, was aimed at reducing SO_2 emissions from the electricity sector. US efforts have also included NO_x reductions through Title IV. These reductions have been implemented alongside a set of parallel requirements addressing NO_x emissions contributing to local ozone nonattainment (see discussion of US ozone efforts for more details).

Controls on long-range transport. Similar to the EU, the US, has addressed the impacts of acid rain formation by addressing emissions that cut across jurisdictions. For the US, these controls often include emission reductions from bordering or “upwind” states. For example, efforts to address SO_2 emissions that contribute to Acid Rain in the US were addressed through a nationwide program.

---

[1] A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.
[2] http://www.iiasa.ac.at/rains/.

Market-based measures are the major basis of acidification efforts. While many of the earlier regulations are still in effect, including New Source Performance Standards and New Source Review, an emissions trading system for SO_2 emissions from fossil-fuel burning power plants located in the continental 48 states of the U.S. was developed under Title IV of the 1990 CAAA. The program consisted of two phases: (1) Phase I, from 1995 to 1999, covered 263 electric generating units larger than 100 MW with an annual average emission rate in 1985 greater than 3,4 kilograms of SO_2 per kJ of heat input.; and (2) Phase II, beginning in 2000, covering plants with generating units larger than 25 MW and an emissions limit of 8,12 million tonnes, equivalent to an average emission rate of 0,98 kg/kJ.

Caps on emissions were implemented by issuing tradable allowances that in total equalled the annual cap level. Allowances not used in the year they are issued could be banked for future use. Most of the allowances were issued to sources on the basis of each unit's average annual heat input during the three-year baseline period, 1985 to 1987, multiplied by their specified emissions rate, which in turn depended on the plant category. A small share (2,8%) of allowances was sold through an annual auction conducted by EPA to ensure the availability of allowances for new generating units. To comply, sources were required to surrender one allowance for each ton of emissions. A source that had more allowances than it needed to cover its emissions could sell the excess allowances, and sources that required additional allowances to cover emissions could purchase allowances to cover the gap.

The transparent system of the Acid Rain Program in which non-compliance and penalties are well understood led to a near-perfect record of compliance. Because all participating units must have working continuous emissions monitors, there is no question as to the number of allowances that are needed for compliance. A known, significant (roughly ten times greater than the cost of allowances), and automatic economic penalty also encouraged compliance. Transparency and flexibility of the program also allowed little basis for regulated sources to sue or delay compliance. As a result, it became less expensive for firms to comply with the requirements than to avoid compliance by seeking the various forms of modifications that characterize traditional regulatory programs such as exemptions, exceptions, or relaxations of the program's requirements (Ellerman, 2003b). As a result, with the exception of a few very small failures, all power plants have been in compliance with Title IV SO_2 allowance trading requirements in all years (Ellerman 2003b; EPA, 2003a). This near-100 percent compliance is extremely different from command-and-control systems that often grant delays or relaxed requirements to sources that are unable to meet the standards (but are not able to compel over-compliance at other sources to compensate for the resulting emissions increases).

The levels chosen were influenced by the science available at the time, but also by economic and political considerations (NRC, 2004). Today, however, there is evidence in the US that more stringent emission reduction targets may be needed to reduce acidification problems and to achieve other air quality goals. Partly in response, EPA has proposed further emissions controls on SO_2 and NO_x from the electricity sector through the proposed Clean Air Interstate Transport Rule.

SO_2 reduction target is for the entire country. Unlike the EU, the US efforts to control SO_2 emissions have primarily been focused on a national emissions reduction strategy with no delineation of emissions by geographic location (e.g., east versus west). NO_x controls for ozone which can provide reductions towards reducing acidification, however, have been regionally differentiated.

2.3. Ground Level Ozone in the EU

Efforts to address formation of ground level ozone requires emissions reductions of both NO_x and VOCs. Ozone formation depends on emissions of NO_x and VOCs from stationary and mobile sources as well as on solar radiation, which means that the ozone problem is different in the Southern and Northern parts of Europe. Natural emissions of VOC also play an important role. Ozone formation is limited by NO_x in some areas and by VOCs in other areas.

Ozone episodes are more localised than for acidification and eutrophication. The most serious episodes take place in the southern and central parts of Europe e.g. in the Mediterranean countries, the Po Valley, south-eastern France and southern Germany. Ozone episodes in northern Europe are mainly a long range transport problem. In addition, the average ozone background level in the Northern Hemisphere is significant (30-40 ppb) and has increased within the last 100 years.

Ground level ozone is regulated by the CLRTAP, the NEC Directive and some EU air quality directives.

Air quality directives for ozone related to vegetation injuries and human health. The ozone directive sets threshold values and long term goals for protection of vegetation (AOT40, see below) and ambient air concentrations for protection of human health. No limit values are set because no lower limit for damages is identified. The threshold values are based on max. daily 8 hour averages.

Controls on formation of ground level ozone address long range transport. Ozone formation is a regional problem, and cannot be solved solely by local actions in individual conurbations. The third Daughter Directive on ozone under the Air Quality Framework Directive has not set limit values, but target values/ thresholds, based upon a realisation that it is not possible to reduce the ozone concentrations to a non-effect level within shortened time limits.

Integrated assessment modelling (RAINS) was carried out in a similar manner as for acidification and eutrophication as a basis for the negotiations of the NECs between the European countries.. Modelling was carried out for 1990 and different scenarios using the so-called AOT40[3] as an indicator of the effects on vegetation as well as the surrogate AOT60, as an indicator of risk to human health.

NOx, VOCs Reduction Targets Set for Each Country. The above types of integration formed the basis for negotiations on reductions of NO_x and VOC emissions in the individual countries in Europe, and resulted in the Gothenburg Protocol and the NEC Directive. EU controls are also in place to control VOC emissions during storage and distribution of petrol as well as a range of facilities using solvents. The Euro standards for motor vehicles and for quality of fuels are important for limiting VOCs as well as NOx. The target has been to reduce the emissions so as to close the gap between 1990 levels and the critical level[4], in steps by 2010 and 2020.

2.4. Ground Level Ozone in the US

Efforts to address formation of ground level ozone include emissions reductions of NO_x and VOCs, but recent focus has been on NO_x. Throughout the 1970s and most of the 1980s, VOCs were the primary focus of ozone mitigation efforts – the role of NO_x was not well understood and was not considered important to ozone nonattainment. With areas still in nonattainment in the mid-1980s and unlikely to meet the 1987 nonattainment deadline, California began to control NO_x emissions, and new reports in the late 1980s uncovered additional sources of VOC emissions that effectively altered the VOC to NO_x ratios in many locations, and identified the important role that NO_x control played in ozone formation. As such, later emphasis has focused primarily on NO_x emissions reductions, with some nonattainment areas focusing on VOC controls.

Controls on ozone precursors have been taken on stationary and mobile sources at the national, regional, and local levels. The US has adopted a variety of emissions controls for contributors to ozone formation through market-based measures, traditional command-and-national approaches, and hybrids. For example, national mobile source NO_x and VOC controls have been introduced through the light-

---

[3] The sum of the differences between the hourly ozone concentrations in ppb and 40 ppb for each hour when the concentration exceeds 40 ppb, using daylight hours only.

[4] The concentration of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur, according to present knowledge

duty vehicle and trucks Tier I emissions standards, National Low Emission Vehicle Program, Inspection and Maintenance, reformulated gasoline, evaporative controls, and reid vapour pressure controls. These mobile source programs have primarily utilized command-and-control approaches. National stationary source controls on NO_x and VOC have been adopted through the Acid Rain program, NO_x State Implementation Plan Call, synthetic organic Chemical Manufacturing Maximum Achievable Control Technology for the chemical industry, and solvent and coating controls. In addition, through the development and implementation of State Implementation Plans, a number of emissions controls have been introduced by state and local governments.

Controls on long-range transport. Investigators soon learned that the NO_x emissions of concern were not just local emissions but also emissions from upwind (due in large part to the tall stacks that were installed in the mid-1970s to avoid local health effects). This knowledge was further advanced with modelling conducted in the late 1990s which helped pinpoint the upwind contributions to ozone formation in the Northeast, upper Midwest and even in parts of the South. As a result, US efforts have sought to address the regional transport nature of ozone precursors. For example, the NO_x SIP Call and the proposed Clean Air Interstate Rule (the "transport rule") places controls on "upwind" sources that contribute to ozone formation in "downwind" areas.

Recent focus has been placed on 8-hour ozone. A new standard for ozone—the 8-hour ozone standard—was finalized in 2004. The new standard seeks to address adverse impacts associated with longer exposures to lower levels of ozone pollution. The 8-hour standard was devised based on updated scientific knowledge of ozone and the understanding that ozone concentrations may have adverse health impacts at levels at or below the old 1-hour standard, particularly in children and adults engaged in outdoor activities. In April 2004, EPA designated and classified nonattainment areas with this new standard and required newly designated nonattainment areas to submit reduction plans (SIPs) by 2007.

Market-based measures have been implemented at a number of geographic scales for ozone precursors. A number of emissions trading programs for ozone precursors have been implemented at the local and regional levels. In 1994, jurisdictions in the Ozone Transport Commission (the Northeast and mid-Atlantic) established a "NO_x Budget Program" to control NOx emissions from electric utility and large industrial boilers. The program has established a cap-and-trade system for the entire region during the May to September ozone season. In the mid-1990s, Eastern states concerns with the impact of Midwestern states' emissions on their air quality led to the EPA developed an emissions trading system known as the "NO_x SIP Call." Under this system, EPA established NO_x emissions caps for 19 member states and the District of Columbia based the cost-effectiveness of achieving emissions reductions in the state and that state's contribution to the problem rather than its attainment status with its SIP. States deemed to contribute to ozone nonattainment were given NO_x emission budgets and may choose to participate in an interstate trading program to reach compliance with the SIP Call by accepting the major elements of a trading program defined in EPA's model rule. More recently, EPA proposed a new rule, the Clean Air Interstate Rule (e.g., "Transport Rule"), which seeks to reduce interstate transport of fine particulate and ozone pollution to help states meet the new 8-hour ozone and fine particulate air quality standards. This rule would establish annual emissions caps in two phases (2010 and 2015) for NO_x and SO_2 in 28 states and the District of Columbia.

At the local level, a number of emissions trading systems have been implemented to control NO_x and VOC emissions. The Regional Clean Air Incentives Market (RECLAIM) NO_x emissions trading program in the South Coast of California applies to over 350 affected electric power plants and industrial sources emissions banking was not permitted. In 2000, the Illinois EPA launched a cap-and-trade program, the Emissions Reduction Market System (ERMS) to reduce VOC emissions in Chicago, a severe ozone non-attainment area. A handful of open-market trading (OMT) programs were established in the late 1990s to add compliance flexibility and lower the cost of reducing NO_x and VOC emissions by extending the universe of emission reduction sources.

The rate of compliance with a number of the specific regional and local emission trading programs has been high. Between 1999 and 2001, only 8 sources in the OTC NO_x Budget Program were in violation of their allowance holdings. The annual rate of compliance under RECLAIM was also high, ranging from 86 percent to 96 percent of total facilities in the period from 1994 to 2000 (EPA 2002b).

NO_x and VOCs Reductions Targets are at the local, state, and regional levels. US efforts to control ozone formation contain efforts at the local level and state level through SIPs and regional measures, as mentioned above. Individual areas are required to develop SIPs to meet the NAAQs. These SIPs contain measures at a variety of geographic levels.

3. ASSESSMENT OF THE EFFECTIVENESS

3.1. Environmental Achievements

To understand the environmental achievements attained in the EU and US and to compare these achievements, the trends in two factors are considered: emissions levels and environmental impact. The time periods chosen— 1980, 1990, and 2001—are meant to show time frames that correspond to periods before major air quality efforts were undertaken and those during the major efforts.

3.1.1. Emissions

The EU-15 and the US have achieved emissions reductions of SO_2, NO_x, and VOCs since 1980. The following tables present comparative data for both of these jurisdictions in order to understand their respective accomplishments in reducing emissions.[5] EU-15 data are collected from the Eurostat (and partly from EEA). US emissions data is compiled from the US Environmental Protection Agency (EPA), transportation travel is from the US Federal Highway Administration, and electricity production is from the US Energy Information Administration (EPA, 2003b; EIA, 2003; FHWA, 2004c).). Emissions data from Japan and Canada is from the Organisation for Economic Co-operation and Development (OECD, 2002a). It is important to keep in mind that a number of factors contribute to these emissions reductions, some which are directly related to the effectiveness of the various pieces of legislation and others that are potentially unrelated. The reductions obtained in the EU vary substantially between countries, e.g. were the reductions in SO_2 emissions much higher in Sweden, Austria and Denmark than the average reductions, but their contributions to the emissions are relatively small. Likewise the reductions achieved in the US vary significantly between different portions of the US. In addition to the amounts for the EU shown in *Table 1* and *Figure 1* there is a significant contribution from ships in domestic seas in Europe and the surrounding sea (Baltic Sea, Black Sea, Mediterranean Sea, North Sea and Northeast Atlantic Ocean) on approx. 4000 kt NO_x and 3000 kt SO_2, (EMEP, 2004).

Figure 1 shows total NO_x, SO_2, and VOC emissions in the US, EU-15, Japan, and Canada from 1980 to 2001.

---

[5] All efforts have been made to ensure comparability of the data; however, since the EU-15 and US categorize sectors differently and use different methodologies for calculating emissions there are likely to be differences.

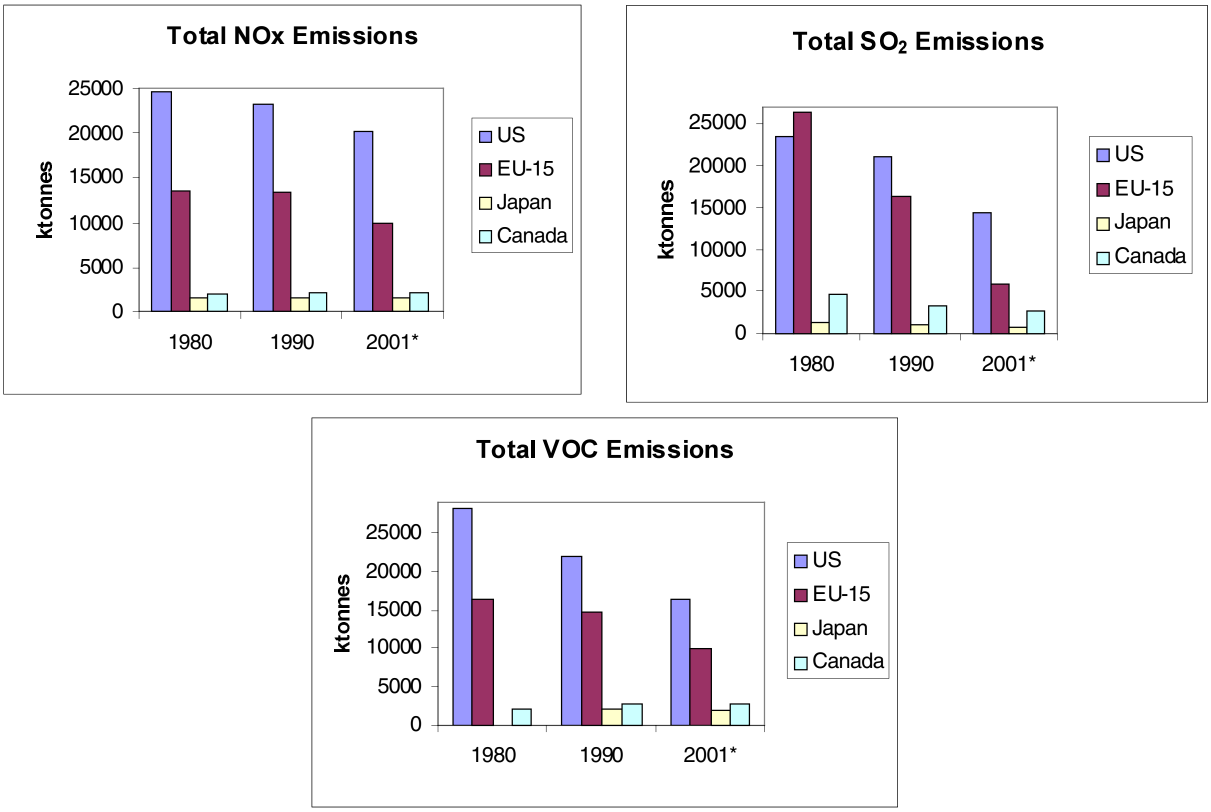


Figure 1 Total NO_x, SO_2, and VOC emissions in the US, EU-15, Japan, and Canada.

Note: * Emissions for Canada shown here are for 1999 for NO_x and 1997 for SO_2 and VOCs. Emissions for Japan shown here are for 1999 for NO_x and 1999 for SO_2 and VOCs.

Table 1 provides information on total NO_x, SO_2, and VOC emissions in the US and EU-15 for all sectors of the economy.

Table 1 Total emissions of NO_x, SO_2 and VOCs in the US and EU-15

		NO_x		**SO_2**		**VOC**	
		US	**EU-15**	**US**	**EU-15**	**US**	**EU-15**
Total Emissions							
1980	Ktonnes	24566	13399	23519	26327	28219	16435
1990	Ktonnes	23161	13334	20936	16333	21878	14664
2001	Ktonnes	20275	9863	14325	5888	16296	9808
2020 (projected)[6]		*N/A*	*5414*	*N/A*	*2230*	*N/A*	*5250*
Emissions Reduction							
1980-2001	Ktonnes	4291	3536	9194	20439	11923	6627
	%	17,5	26,4	39,1	77,6	42, 3	40,3
1990-2001	Ktonnes	2886	3471	6611	10445	5581	4856
	%	12,5	26,0	31,6	64,0	25,5	33,1

Efforts to reduce emissions that contribute to acidification have achieved significant reductions in both regions, particularly for SO_2. Since 1980, the EU-15 and US have reduced SO_2 emissions by 77,6 and 39,1 percent, respectively.

---

[6] No consistent projections are available for the US for these emissions. Projections are available for individual sources (e.g., electric generating units), but not consistently for all sources. The projections for EU-15 are from "RAINS WEB (version August 2004)", http://www.iiasa.ac.at/web-apps/tap/RainsWeb/.

The reductions in NO_x and VOC emissions are smaller but also significant, especially after 1990[7]. Since 1980, the EU-15 has achieved a reduction in NO_x emissions of 26,4 percent and the US of 17,5 percent. In the EU-15, the reduction in NO_x is mainly due to introduction of three way catalysts on all new cars. Similarly, VOC emissions have been reduced by 40,3 and 42,3 percent in the EU-15 and US, respectively. Large reductions of the NO_x, SO_2 and VOC emissions have been obtained in some of the new EU Member States, but the reductions vary significantly from country to country; for further information see table 8 of the EU report.

Since the EU-15 and US both have different population and GDP levels, another way to look at total emissions is to consider per capita and per GDP total emissions (see *Table 2*). Emissions per capita remain significantly higher in the US than the EU-15 for all three pollutants. Since 1980, the US has achieved slightly greater levels of reduction in per capita NO_x emissions than the EU-15 (reductions of 34 percent compared with 31 percent in the EU), while the EU has achieved greater reductions in per capita emissions of SO_2 (79 percent compared with 51 percent in the US). Since 1980, similar percent reductions have been achieved for per capita NO_x emissions—77 and 76 percent for the US and EU-15, respectively—while the EU-15 have achieved greater reductions for SO_2 - 93 and 83 percent for the EU-15 and US, respectively.

Table 2 Total emissions of NO_x, SO_2 and VOCs by per capita an per GDP in the US and EU-15

		NO_x		**SO_2**		**VOC**	
		US	**EU-15**	**US**	**EU-15**	**US**	**EU-15**
Emission per capita							
1980	kg/person	108,4	37,7	103,8	74,1	124,6	46,3
2001	kg/person	71,5	26,0	50,5	15,5	57,4	25,9
Emission per GDP							
1980	Kg/M€	7156	3433	6851	6745	8220	4210
2001	kg/M€	1627	827	1150	494	1756	823

Emissions in relation to GDP are considerably lower in the EU-15 than in US. Significant reductions of emissions in relation to GDP[8] were also observed in both regions, which could indicate a certain degree of de-coupling between emissions and economy in EU-15 and US, with the EU-15 appearing to have somewhat more success in this.

In both regions, further progress in reducing SO_2 and NO_x emissions is expected between 2001 and 2010 and possibly beyond. In the EU-15, achieving the NECs will require larger reductions between now and 2010. In the US, greater SO_2 reductions as outlined in current legislative and regulatory proposals will likely be achieved as a part of efforts to control PM, ozone, and acidification. In addition, efforts to address regional haze could lead to greater reductions as well.

While overall progress in reducing emissions in these two regions has been achieved, the progress among the dominant sectors has varied. *Figure 3* shows total NO_x and SO_2 emissions in the US, EU-15, Japan, and Canada from "energy industries".[9] *Table 3* provides information on NO_x and SO_2 emissions in the US and EU-15 for energy industries.

Emissions from energy industries in both regions have declined significantly over this time period. In both regions, most of the emissions reductions have occurred since 1990 (see *Table 3*). The EU-15 achieved greater emissions reductions of SO_2 and NO_x (33 and 16 percent, respectively) prior to 1990

---

[7] NO_x is measured here and in the following tables as NO_2 emissions.

[8] GDP is in current prices based upon calculations of the OECD and current PPPs.

[9] In the U.S., this information is classified by EPA as "Fuel Combustion: Electric Utilities". Canada and Japanese data is for "power stations".

than the US (9 and 5 percent, respectively). This trend has continued into the 1990s as the EU-15 succeeded in again achieving greater SO_2 and NO_x reductions than the US.

Both regions have achieved large reductions in the SO_2 and NO_x intensity of electricity generation, see *Table 4*. Since 1990, the EU-15 has achieved a reduction in NO_x per MWh of 40 percent (with an emissions per unit of electricity rate 65 percent lower than the US), while the US has achieved a 42 percent reduction. Over the same period, EU-15 and US SO_2 emissions per MWh declined by 70 and 47 percent, respectively. Despite these reduction levels, US emissions per unit of electricity (with nuclear and renewable energy generation excluded) are higher than in the EU-15 for NO_x, SO_2, and VOCs.

Table 3 Energy industry emissions of NO_x and SO_2 in the US and EU-15

		NO_x		**SO_2**	
		US	**EU-15**	**US**	**EU-15**
Emissions from Energy Industries					
1980	Ktonnes	6372	3360	15848	15078
1990	Ktonnes	6045	2829	14432	10039
2001	Ktonnes	4437	1681	9871	5135
2020 (projected)[10]	Ktonnes	*N/A*	*813*	*N/A*	*620*
Emissions Reductions					
1980-2001	Ktonnes	1935	1679	6031	11484
	%	30,4	50,0	38,1	76,2
1990-2001	Ktonnes	1608	1148	4615	6445
	%	26,6	40,6	32,0	64,2

Further reductions in the US are expected for NO_x and SO_2 emissions for the energy industry as a result of implementation of existing programs, such as the NO_x SIP Call, and legislative and regulatory proposals, such as the Clean Air Interstate Rule.

Table 4 NO_x and SO_2 Emissions per unit of electricity from emitting sources in the US and EU-15

		NO_x		**SO_2**	
		US	**EU-15**	**US**	**EU-15**
1990	Kg/MWh[11]	2,9	1,72	6,9	7,5
2001	Kg/MWh[8]	1,6	1,04	3,6	2,2
Reduction (1990-2001)	*%*	*42,3*	*39,5*	*46,5*	*70*

While it is impossible to completely separate all the factors that contribute to the differences in emissions from the energy industry in the two regions as a part of this study, a number of factors can help partially explain the differences. Some of the factors driving these differences are related to environmental policies, while others are a result of other factors, such as broader energy policies and weather.

For example, the share of power generation from air pollutant emitting sources in the US is higher—73 percent—than the EU-15—52 percent—in 2001.[12] *Figure 2* shows the share of electricity generation by type in 2001. As can be seen, the EU-15 generates significantly less electricity from coal and a

---

[10] The projections for EU-15 are from "RAINS WEB (version August 2004)", http://www.iiasa.ac.at/web-apps/tap/RainsWeb/.

[11] Includes for the EU electricity generation and district heating, which not is separated in the emissions inventories for EU-15. It is estimated to be 5-10%. Electric generation from renewable and nuclear power is not included.

[12] For emitting sources, we include generation from coal, petroleum, natural gas, other gases, wood, and waste.

considerably larger amount from nuclear and hydro than the US. The share of generation from natural gas is essentially the same.

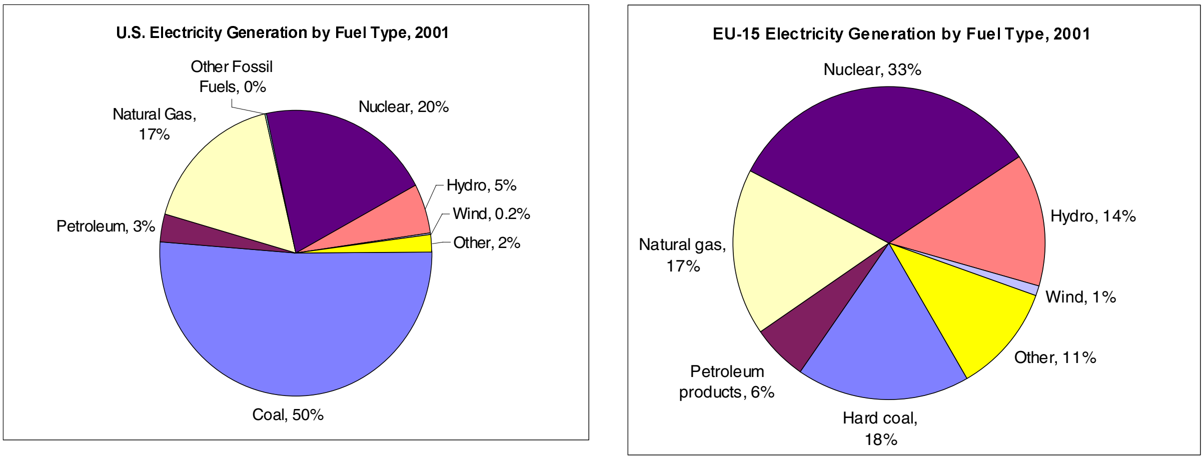


Figure 2 Share of US and EU-15 Electricity Generation by Type in 2001

In addition, energy consumption differences between the two regions can also help explain differences in total emissions from the energy industry. Energy consumption in the EU-15 is significantly lower than for the US. In 2001, per capita energy consumption in the EU-15 was 6,0 MWh per capita compared to 12,9 in the US (IEA, 2003).

Figure 3 shows total NO_x, SO_2, and VOC emissions in the US and EU-15 from transportation sources.

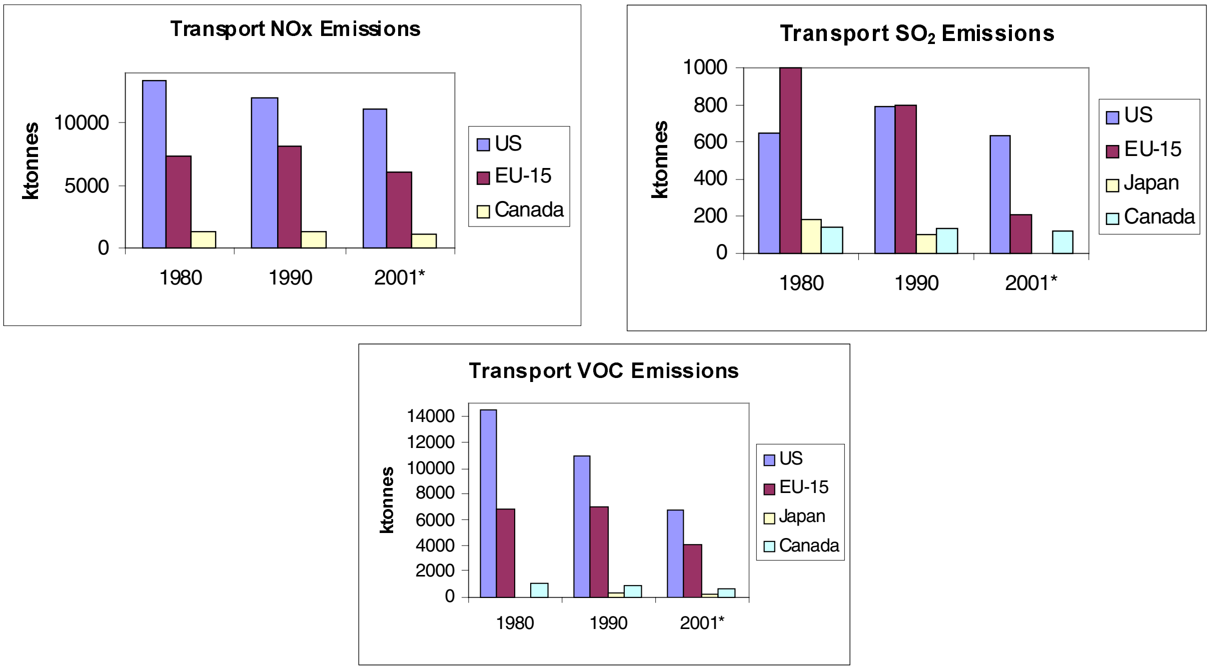


Figure 3 Total NO_x, SO_2, and VOC emissions in the US, EU-15, Japan, and Canada from transportation sources.

* Emissions for Canada shown here are for 1996 for NO_x and 1997 for SO_2 and VOCs. Emissions for Japan shown here are for 2000 for road transport NO_x and VOCs and 1999 for other transport VOCs.

Table 5 shows total NO_x, SO_2, and VOC emissions in the US and EU-15 from transportation sources.

Table 5 Transport emissions of NO_x, SO_2 and VOCs in the US and EU-15

		NO_x		SO_2		VOC	
		US	**EU-15**	**US**	**EU-15**	**US**	**EU-15**
Total Transport Emissions							
1980	Ktonnes	13467	7420	650	996	14570	6822
1990	Ktonnes	12133	8095	793	804	10933	6962
2001	Ktonnes	11254	6084	636	207	6800	4074
2020 (projected)[13]	Ktonnes	*N/A*	*2342*	*N/A*	*212*	*N/A*	*753*
Emissions Reductions							
1980-2001	Ktonnes	2214	1336	14	789	7770	2748
	%	16,4	18,0	2,2	79,2	53,3	40,3
1990-2001	Ktonnes	880	2011	157	479	4133	2888
	%	7,3	24,8	19,87	90,1	37,8	41,5
Emissions per capita							
1980	kg/person	59,4	20,9	2,9	2,8	64,3	19,2

Both regions have achieved greater NO_x reductions from road transport than other transport since 1980 *Table 6*. The EU-15 has achieved a reduction in road transport NO_x emissions of 23 percent, compared to less than 1 percent for other sources since 1980. The US has reduced NO_x emissions from road transport by 28 percent over this period, while other transport emissions have increased by 28 percent.

Table 6 On-road emissions per unit of travel of NO_x, SO_2 and VOCs in the US and EU-15

		NO_x		SO_2		VOC	
		US	**EU-15**	**US**	**EU-15**	**US**	**EU-15**
Emissions Per Unit of Travel							
1980	*kt/(km/vehicle)*[14]	0,68	0,38	0,02	0,04	0,83	0,42
1990	*kt/(km/vehicle)*	0,49	0,43	0,03	0,36	0,48	0,43
2001	*kt/(km/vehicle)*	0,39	0,30	0,01	0,004	0,23	0,24
Reduction in Emissions Per Unit of Travel							
1980-2001	kt/(km/vehicle)	0,29	0,08	0,01	0,036	0,59	0,18
	%	42,5	22,0	46,9	91,8	71,8	43,1
1990-2001	kt/(km/vehicle)	0,09	0,13	0,01	0,33	0,24	0,20
	%	19,1	30.5	51,2	90,0	51,1	45,1

Emissions per unit of travel for road vehicles (kt/(km/vehicle)) are higher in the US than the EU-15—0,39 and 0,30 for NO_x, respectively (see *Table 6*). This intensity has declined to a greater extent in the US since 1980—a 43 percent reduction for the US and 22 percent for the EU-15. This can in large part be explained by the high intensity in the US in 1980 compared to that of the EU-15. Since 1990, the EU-15 has achieved a greater reduction in vehicle NO_x intensity than the US -- 31 percent compared to 19 percent -- due to introduction of three way catalysts on all new petrol cars from the early 1990s.

3.1.2. Environmental Impact

As a result of these emissions reductions, there has been a marked improvement in a number of the environmental criteria associated with acidification, eutrophication and ground level ozone. Presented below is information comparing the environmental impact of these emissions reductions in the respective locations. *Figure 4* shows the wet deposition of sulphate in Europe and the US in 1989 and 2001 and *Figure 5* shows the wet deposition of nitrate (in kg/ha).

---

[13] The projections for EU-15 are from "RAINS WEB (version August 2004)", http://www.iiasa.ac.at/web-apps/tap/RainsWeb/.

[14] The total emission divided by the average annual mileage of the vehicles in the fleet (i.e. the emission when the whole vehicle fleet drives 1 km). The average emission factor can be calculated by division with the total number of vehicles.

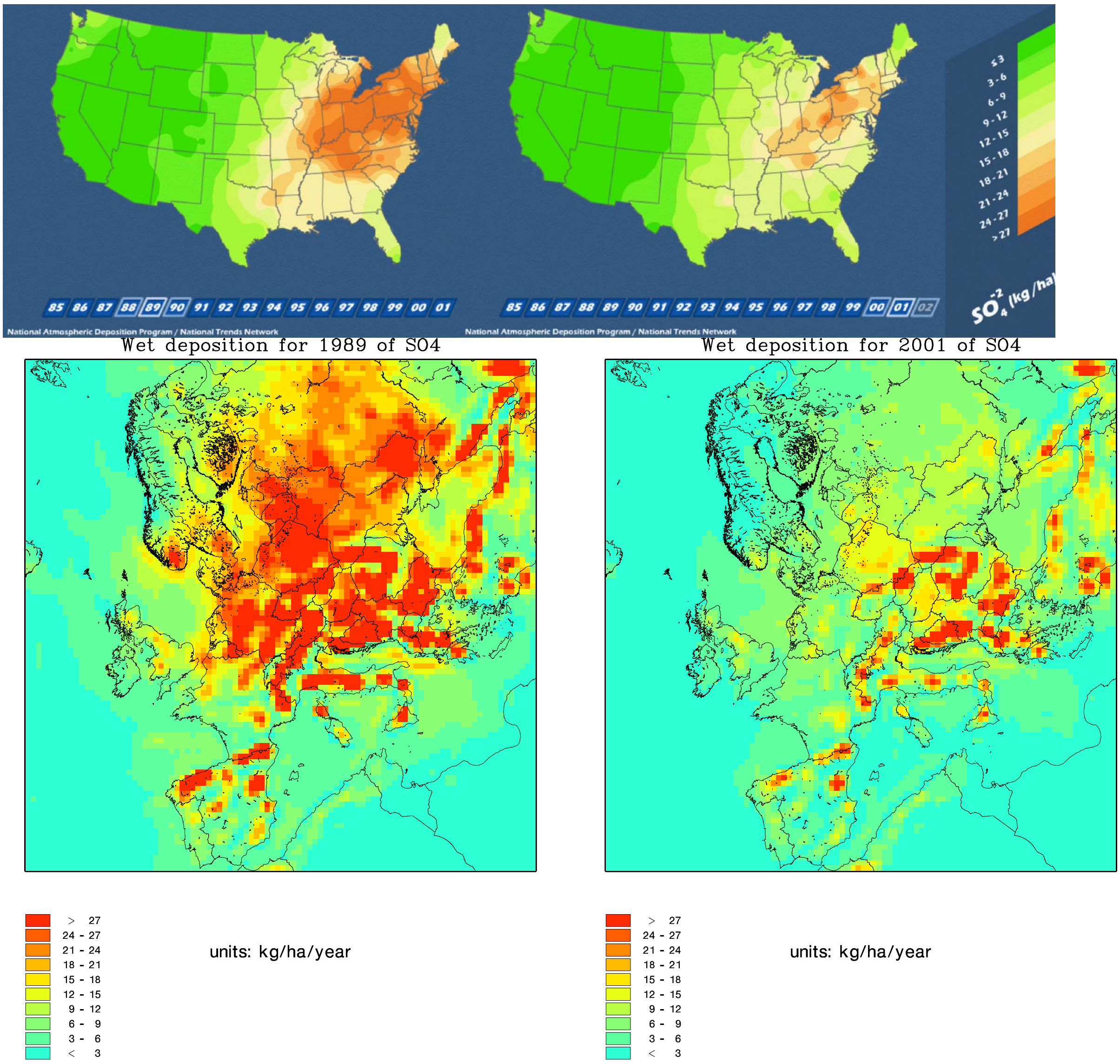


Figure 4 Wet deposition of sulphate in the US and Europe in 1989 and 2001 (NTN, 2004; Brandt and Christensen, 2004)

Note* The scales and intervals in the graphs are the same, but the colours are a little different due to the reproduction of the maps.

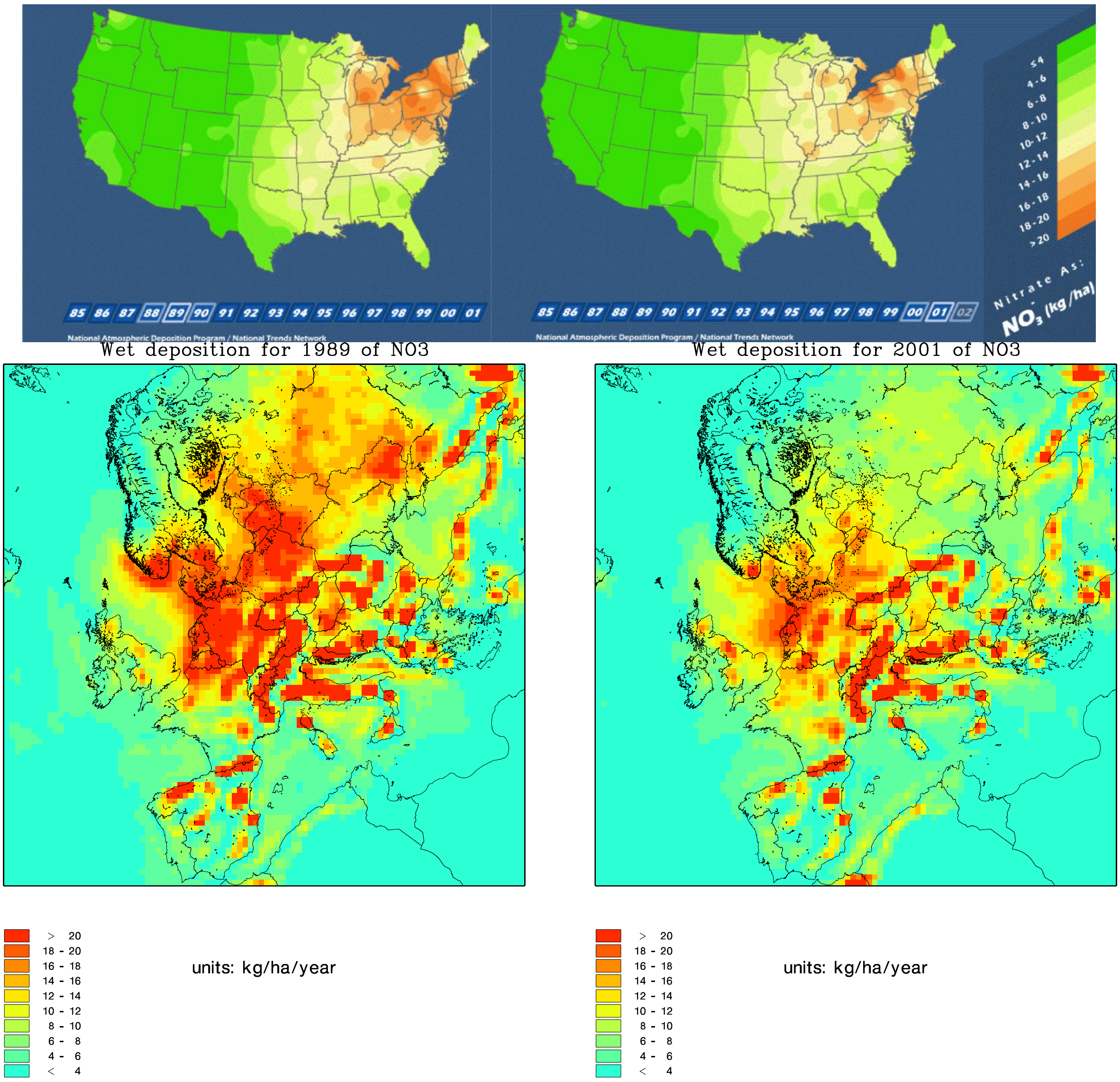


Figure 5 Wet deposition of nitrate in the US and Europe in 1989 and 2001 (NTN, 2004; Brandt and Christensen, 2004)

Note* The scales and intervals in the graphs are the same, but the colours are a little different due to the reproduction of the maps.

As can be seen above, there has been a reduction in the level of sulphur and nitrate deposition in both the EU and US, and pictures are generally the same. Emissions reduction efforts in both the EU-15 and US have had the largest impact on sulphur deposition since SO_2 reductions were a major focus of efforts to reduce acidification in both jurisdictions. Nitrate deposition was reduced to a lower extent, mainly due to lower reduction in NO_x emissions. While it is impossible to completely compare the level of acidification between the two regions, in both regions there are still areas where wet deposition of sulphate and nitrate is occurring in high concentration levels, implying that greater reductions may be needed in the future. In regions, targets and regulations being developed for the 2000-2020 timeframe will likely have an impact in this regard.

Trends in ozone concentration in the two regions can also show the progress of efforts to address ozone formation. *Figure 6* shows the annual average ozone concentration in the US and Europe in 1994 and

2001.[15] (Note: The scales and colours of the US and EU maps are different for each figure. The US maps are in ppm, while the EU maps are in ppb.)

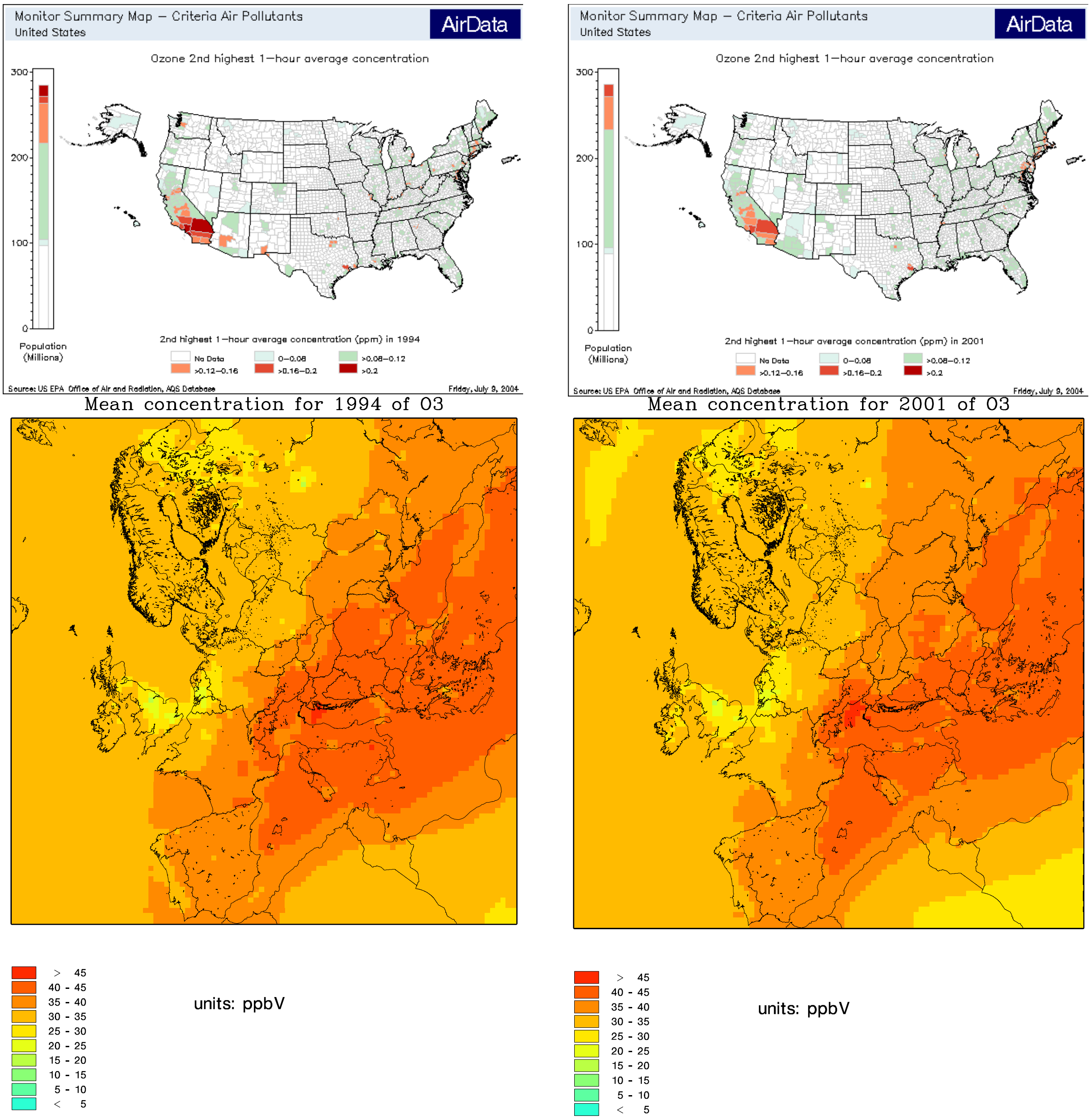


Figure 6 Annual average of ozone in the US and Europe in 1994 and 2001 (EPA, 2004g; Brandt and Christensen, 2004)

Note: Due to data differences in the US and EU and scales, the US map is in parts per million (ppm), while the EU data is in parts per billion (ppb); 1 ppm is equal to 1000 ppb. The data from US are measured data and the data from Europe are based on model calculations.

Since ozone formation can vary from year to year depending on such factors as weather, it is also important to see trends in concentration to understand if one year snapshots, as shown in *Figure 6 are* one year anomalies. *Figure 7* shows the annual mean one-hour ozone concentrations in both regions over time. The data are not directly comparable due to different settings of limit values and the

---

[15] In order to show consistent maps for Europe and the US, we could only show concentrations going back as far as 1994. Maps from the US prior to this year, differ from those produced more recently.

monitoring strategies are related to these. As can be seen in *Figure 7*, average ozone concentrations in both regions were nearly constant between 1995 and 2001 and the same is the case for the peak values (episodes). Ozone episodes were less frequent in the recent years in Northern Europe, probably due to the reductions of NO_x and VOC. The general ozone level is also determined by the high hemispheric background, which is 30-40 ppb as annual average. UNECE stated in 2002[16] that throughout the Northern Hemisphere, current emissions create pollution levels that exceed air-quality objectives. While local or regional pollution, such as car emissions or industrial emissions, and environmental conditions are responsible for most of these exceedances, there is now scientific evidence that air quality is also influenced by emissions, transport and transformation processes elsewhere in the Northern Hemisphere. There is well-documented evidence for intercontinental and hemispheric transport of ozone and the precursors, which adds to local background pollution. For instance, when summer smog with high levels of ozone hit European cities, a significant part may be due to sources in Asia and North America. Likewise, European cars and trucks add to excessive ozone levels in Siberia. The current levels of emissions from Asia, North America and Europe have increased the hemispheric burden of ozone by at least 50% since the Industrial Revolution. Any further increase in Northern Hemispheric emissions will make it more difficult to reach local air-quality objectives through local or national measures alone.

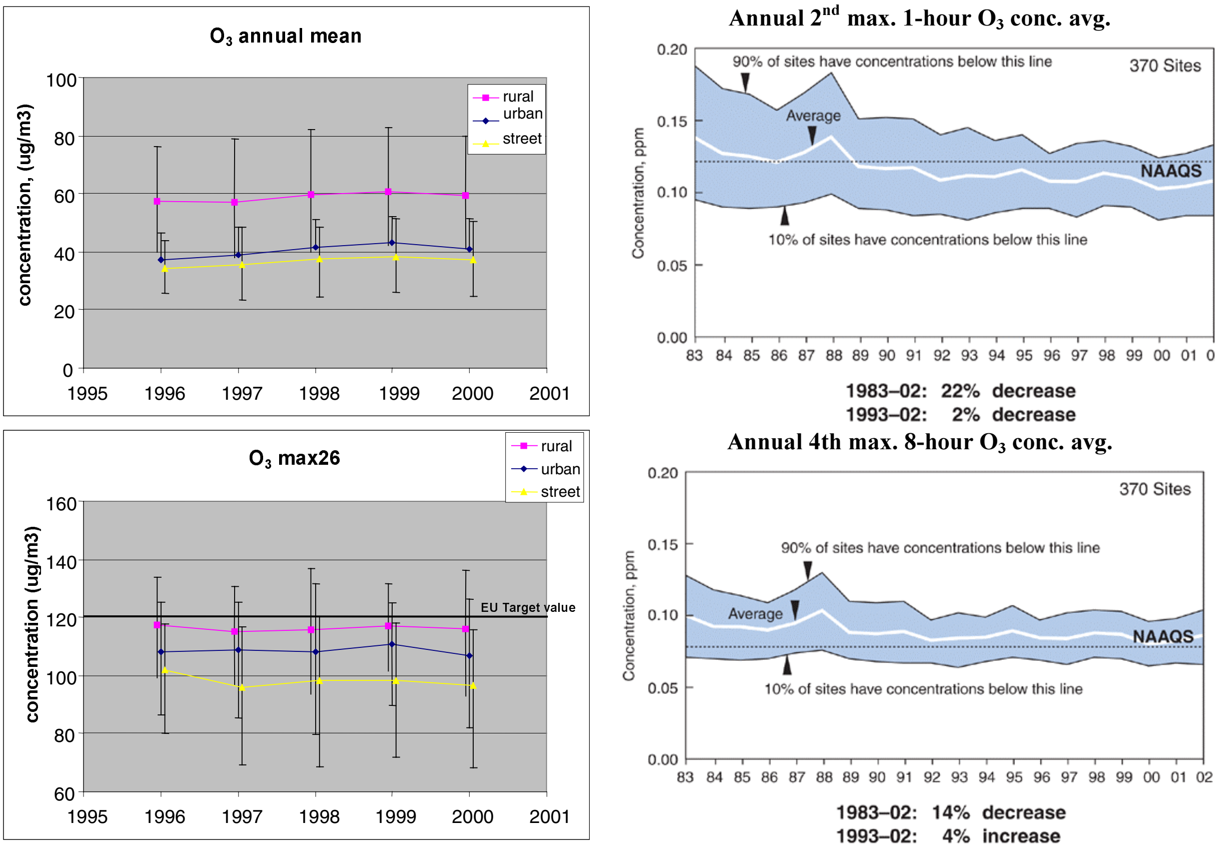


Figure 7 The trends of ozone in EU (EEA, 2003c) and US measured at different types of locations (EPA, 2003c).

Note: The figures from the two regions are not directly comparable due to different monitoring strategies, and the graphs are produced in relation to the strategies/limit values by EEA and EPA respectively for the EU and the US. The Figure for the EU-15 separately shows monitored data at rural, urban and street sites, while the US figure reports data for all monitored sites which contain some mix of rural, urban and street sites. Further, comprehensive data in the EU are only available after mid 1990s.

---

[16] United Nations Economic Commission for Europe, Press release. Geneva 11 October 2002.

Ultimately, the aim of any ozone reduction program is improvements in health. Unfortunately, health impacts are difficult to assess for a number of reasons. Therefore, it is difficult to show trends in the health impacts of the ozone efforts in the two regions. As seen from Figure 7 the ozone level is higher at rural sites than in urban sites and in streets because ozone is removed by reaction with NO to form NO2, which has more less the same effect on health as ozone. The total assessment of the health effects has to be based on ozone as well as NO2 exposure. The number of people living in areas with high ozone levels is one potential proxy measure for ozone impacts. In the EU, the number of people exposed to ozone levels above the EU target value of 120 µg/m3 (8 hours average to be exceeded not more than 25 times per year) is estimated to be about 18 million (EEA, 2004). No clear trend has been observed since mid 1990's, see Figure 7. In the US, the number of people living in counties with ozone concentrations that exceed the 1-hour ozone standard was 37 million in 2003—a decline from 59 million in 1998. Similarly, the number of people living in counties that exceed the 8-hour ozone standard was 100 million in 2003—a decline from 146 million in 1998.

3.2. Costs

The costs of the emissions reductions mentioned above are another important indicator in considering the effectiveness in the two jurisdictions. Below we present summary information on the cost of the emissions reductions by considering three factors: level of technological innovation, costs versus benefits, and cost-effectiveness. Ultimately it would be useful to compare these three factors between the US and EU-15. However, complete comparability of costs proved difficult for a variety of reasons, partially because the results were reported considering programs on different scales, using different methodologies, and looking at different factors. Therefore, below, we present the results from these two regions and do not attempt to compare results which are potentially not directly comparable.

3.2.1. Technological Innovation

In Europe, very strong political and public pressure in connection with the debate about "forest death" in the 1970s led to "command-and-control" regulatory action in several countries, and this helped to spur some technological innovation. For example, in Germany, a 1983 ordinance gave electricity companies a very short deadline to comply with new and very strict emission limit values. This first led to adding of lime to the flue gas. Later, desulphurization technology became available to the companies. The final result was higher reduction efficiencies than had first been anticipated.

Economic incentives such as emission taxes have also played a role in encouraging technological innovation in several European countries. A study to evaluate economic incentives in France and Sweden concluded that the Swedish programme with a rather high NO_x charge, and with return of the money to the firms in proportion to the production of energy, was the most effective. The administrative cost was only 0,2-0,3% of the revenue. The Swedish NO_x charge provided a strong incentive both for fuel switching, modifications to combustion engineering and the installation of specific abatement equipment such as catalytic converters and selective non-catalytic reduction. The Swedish NO_x charge has also implied a strong incentive to use the equipment, to fine tune combustion and other processes in such a way as to minimise emissions. This led to a reduction in the average emission factor from 0.41 to 0.25 kg NO_x/MWh between 1992 and 2000.

European efforts to achieve emission reductions have also provided impetus for energy efficiency innovations. From 1994 to 1998, EU generation from Combined Heat and Power (CHP) increased from 9% of gross electricity generation to 11%, 7% short of the EU indicative target of 18% by 2010. Penetration of CHP in Denmark and the Netherlands is particularly high (more than 50%) as a result of government support. Liberalisation of energy markets in Finland and the United Kingdom has stimulated investment in CHP. However, lower electricity prices may act against more investment in CHP plants, which are capital intensive. This has already been the case in Germany where CHP generation has decreased.

The US Acid Rain Trading Program has led to technological innovation in two regards. First, rail deregulation lowered the costs of low sulphur coal, making this an economic compliance option for many generators. The flexibility of the acid rain trading program enabled facilities to take advantage of this opportunity, lowering allowance prices and compliance costs for participants.

Second, the costs of scrubber technology in Phase I came down from a total cost of \$0.51 per kg to \$0.32 per kg, largely due to reductions in the fixed and variable operation and maintenance costs from improved instrumentation and control, reducing the parasitic loss of power and manpower requirements, and a 25 percent increase in the utilization of scrubbed plants (Popp, 2001). This higher utilization of scrubbed plants resulted from the fact that scrubber operating costs are lower than allowance costs, and because plants burning low sulphur coals now faced a premium fuel cost over the higher sulphur coals burned by scrubbed plants. On the other hand, the NO_x standards were based on implementation of low-NO_x burners. Because the Alternative Emission Limit compliance option allowed plants to comply even if the limit wasn't achieved with installation of the technology, there was little incentive to take the risks needed to develop alternative compliance methods.

3.2.2. Costs Versus Benefits

For Europe as a whole, the total cost of reaching the emission ceilings is expected to be about 70 billion euros (US\$ 75 billion) a year. This includes the cost of several other European initiatives that will contribute to meeting the emission ceilings, such as the European Union directives. The benefits of meeting the Protocol's emission ceilings have been estimated at roughly 200 billion euros (US\$ 214 billion) a year. These benefits largely result from significant reductions in the negative effects of ozone and particulate matter on human health.

The benefit by reduction of SO_2 has been estimated (ExternE) at 6100 \$/t SO_2, of which the major part (4000-5000 \$/t SO_2) is related to human health and especially secondary particles. The benefit by reduction of NO_x has been estimated at 5000 \$/t NO_x, of which the major part (3000-4000 \$/t NO_x) is related to human health and especially secondary particles.

In the US, the annual benefits of the acid rain SO_2 regulations (\$78 to \$79 billion dollars) far exceeded the costs (\$1 to \$2 billion dollars) during the early years of the acid rain trading program (OMB, 2003). Similarly, acid rain NO_x regulations resulted in annual benefits of \$1 to \$5 billion and costs of \$372 million (OMB, 2003). These values are not directly comparable with the estimates for achieving the NECs, described above, since achieving the NECs includes reductions of NO_x and VOC in addition to SO_2.

In addition, the administration of the Acid Rain Trading program has been estimated to be relatively low cost. Actual costs to EPA to implement the Acid Rain Program during the five years following the Clean Air Act Amendments came to \$44 million, or 4 percent of total costs to implement the Clean Air Act in the same period. The administrative costs of the conventions and the EU directives are not estimated.

3.2.3. Cost Effectiveness

One of the classic criticisms of command-and-control measures such as those used in the EU is that this type of control approach is not cost-effective. However, one study of the German effort to address acidification concluded that it was likely that the command-and-control approach used was in fact cost-effective. Since the policy aim was to reduce SO_2 emissions to a very high extent as soon as possible and this required all sources to reduce their emissions to the extent that it was technically feasible, little scope remained for differentiation among abatement activities and a reallocation by means of e.g. emissions trading would not have produced any cost savings (Wätzold/Hansjürgens, 2002).

A recent analysis of costs for the UK after adoption of the UNECE Protocols on acidification and the 1988 Large Combustion Plant Directive found that costs increased by only 2.5% to 5% over a 15-year period. In contrast, *ex ante* forecasts had projected that costs would lead to increases in electricity generating costs of up to 30% (based on the assumption that plant would need to be fitted with flue gas desulphurisation equipment).

It is difficult to find marginal abatement costs for the EU that are comparable to abatement costs in the US. The cost estimates used in the RAINS model in Europe include different technologies, the fuel type, sulphur content in the fuel, etc. Nonetheless, abatement costs for reducing emissions in the EU from large combustion plants have been estimated (ExternE) to be between 600 and 1200 \$/ton SO_2 by wet limestone scrubbers or spray dry scrubbers and between 1100 and 1700 \$/ton NO_x by SNCR and between 1600 and 4000 \$/ton NO_x by SCR.

An indicator of program efficiency for the US Acid Rain Trading program is the allowance price. Allowance prices for SO_2 ranged from a low of \$70 per tonne in early 1996 to highs slightly above \$220 per tonne in 1999 and 2001. Current prices are approaching \$440 per tonne due to market expectations for tighter future requirements (Air Daily, June 18, 2004). Investigators differ on the relative cost-effectiveness of the US acid rain control program. In part, results depend on whether one compares the effects with the ex ante projected costs of an SO_2 control program or the likely costs of a non-trading scenario that factors in the effects of various exogenous changes that took place that were unrelated to establishment of the acid rain trading program.

Ex ante cost estimates for the fully phased-in acid rain trading program, assuming compliance with a traditional technology-based program requiring scrubbers at all units—the alternative under consideration in 1990-- range from \$3.5 to \$7.5 billion per year, while current estimates of compliance costs in 2010 are just over \$1 billion per year—a significant savings (Ellerman, 2003b). Trading allowed sources to use a variety of compliance methods, ranging from end-of-pipe scrubber technology, to fuel switching to low sulphur coals, to dispatch changes, to purchase of allowances from other sources. While there is no question that the acid rain trading program achieved significant cost savings over what was predicted ex ante, there is some disagreement over the degree to which the emissions trading mechanism was responsible for these savings. Two groups of investigators sought to understand the cost savings associated with the acid rain trading system versus a (fictional) mandatory compliance regime that allows for flexibility in meeting a given emission rate target. One group of researchers found that the actual cost of complying with Title IV in 1995 and 1996 was \$30 to \$130 million more than the cost of a benign command-and-control alternative, and significantly greater than the estimated cost of a fully efficient trading program, while a second group of researchers found that cost savings of \$350 million per year have been realized in the early years of phase one.

3.3. Competitiveness

A recent analysis found that environmental controls in Europe had not placed European industries at a competitive disadvantage vis a vis operations in other countries (Watkiss et al., 2004). The study concluded e.g. that:

- Costs arising from environmental technology (integrated process measures) are often counterbalanced by cost reductions due to improvements in technology, so that there are no price rises or decreases in profitability overall. However, in the case of end-of-pipe technologies, this counterbalancing effect is less obvious.

- Industrial air pollution expenditures as percentages of industrial GVA expenditures appear to be similar in EU-15 and the US but greater in both than Japan. However, since these expenditures are less than 0.5% of industrial GVA in all three world regions, the competitiveness effects are likely to be limited.

- The statistics on air pollution expenditures suggest broadly similar absolute levels of expenditures between Europe, US and Japan.

- As percentages of industrial GVA expenditures we find that Japan accounts for the lowest percentage (0.1), whilst the US and the EU-15 are similar (0.4) – which suggests that the potential impacts on competitiveness in the EU and the US will be similar to each other but greater than in Japan.

- However, the size of these percentages suggests that competitiveness effects – and differences in competitiveness effects between regions – are actually small in real terms.

- To date there is very limited evidence for there being significant competitiveness effects resulting from air pollution legislation on a general level.
- In the majority of cases, the pattern of direct costs in both Europe and the US follow a similar pattern –air pollution policy seems to have had less impact on direct costs than originally anticipated, though this is by no means a guarantee that this will remain the case for future legislation.

- Based on historical trends, it would be expected that, relative to major EU competitors, future air pollution legislation in Europe would not be so significant as to have a major effect on international competitiveness. Note however, that a number of important directives have not yet been fully implemented (for example the IPPC directive, the National Emissions Ceiling Directive, Air Quality Framework daughter directives, the amended Large Combustion Plant Directive, and the Greenhouse Gas Emissions Directive), and the cumulative effects of this legislation could still have economic implications.
- However, the US is likely to implement future improvements through market-based instruments, which may offer a lower cost approach for US industry.

4. CONCLUSIONS

While a full comparative analysis between the two regions was limited due to a variety of factors, it is possible to highlight several conclusions for the comparison that we were able to conduct. A number of the conclusions from the consideration of the acidification, eutrophication, and ozone formation case study can help illuminate potential areas for next steps on air quality control. Below are some of the key conclusions from the comparison of the emissions control approaches, emissions reductions, environmental achievements, and costs in the two regions.

- The EU achieved remarkable emission reduction results through a command and control approach, while the US has opted to utilize market-based mechanisms to a greater extent than in the EU-15. The US has utilized emissions trading systems to control Acid Rain and in some areas for emissions related to ozone. Each approach has been uniquely tailored to the given emission of concern and the impacts associated with those emissions. For example, the Acid Rain Trading Program establishes a national cap due to the transport of acidifying pollution, while the NO_x SIP Call was focused on only a portion of the country based upon assessments of transport associated with ozone formation. Canada and Japan have largely utilized command and control approaches for controlling SO_2 emissions.

- A limited number of EU countries have utilized market-based mechanisms, including emissions taxes and charges, but this is not a policy of the EU as a whole. The most successful tax/charge programmes in Europe (e.g. Sweden) were based on relatively high rates and returned most of the money to the companies in relation to the production achieved.

- Critical loads is a concept used more generally in the EU than in the US. The concept has been at the heart of much of the EU goals setting process. The US, on the other hand, has no such formal concept for establishing emissions goals, but has done it using a variety of separate concepts. One reason for choosing the critical loads concept in Europe was that the uncertainties in the relationship between deposition and effects were so large that the role of cost-benefit analysis has been limited. However, the critical loads concept was also used for the negotiation in relation to the most effective emission reductions in the different European countries (the Gothenburg Protocol and the NEC Directive).

- Both EU-15 and US emissions of NO_x, SO_2, and VOCs are higher than those of Canada and Japan. In 2001, US emissions of all three are higher than the EU-15. Further, emissions of the pollutants contributing to acidification are considerably higher per capita and in relation to GDP in the US than in the EU-15. This can have implications for both the effectiveness of the EU air quality rules in light of growing GDP and population, the decoupling of the economy from the environment, and the EU's ability to reduce emissions further.

- Both regions have achieved significant reductions since 1980 of emissions that contribute to acidification, eutrophication, and ozone formation. Greater SO_2 and NO_x reductions have been achieved in the EU-15 (78 and 26 percent) than in the US (39 and 18 percent) since 1980. Likewise Japan and Canada have seen dramatic declines in SO_2 emissions over the period. Japanese SO_2 emissions fell by 82 percent between 1970 and 1992 and by 3 percent between 1990 and 1999. Between 1980 and 2000, Canada's SO_2 emissions had been lowered by 45 percent. Greater VOC reductions have been achieved in the US (42 percent) than in the EU-15 (40 percent) since 1980.

- Emissions of SO_2 and NO_x from energy industries have declined in both regions since 1980. The EU-15 has achieved a reduction in SO_2 and NO_x of 76 and 50 percent, respectively, from these sources. US SO_2 and NO_x emission have declined by 38 and 30 percent, respectively, over this time period. Most of the emissions reductions in both regions have occurred since 1990.

- The intensity of emissions (in kg/MWh) from energy industries is lower in the EU-15 than in the US. Since 1990, the EU-15 has achieved a greater decline in SO_2 intensity (70 percent compared with 47 percent), while the US has achieved a slightly greater reduction in the NO_x intensity (42 percent compared with 40 percent).

- The US has achieved greater reductions in NO_x emissions from transport, but total transport emissions are still higher than those in the EU-15. The EU-15 has achieved greater reductions in transport emissions since the 1990s, while the US has seen a constant decline. Emissions per unit of travel for road vehicles (kt/km/vehicle) are higher in the US than the EU-15—0,39 and 0,30 for NO_x, respectively.

- Both regions have achieved greater NO_x reductions from road transport than other transport since 1980.

- Large reductions in sulphate deposition have occurred in both regions; however, some areas in both countries suffer from high levels of sulphate deposition. Limited progress has been made on nitrate deposition in both regions.

- NH_3 is mainly an environmental problem in the Northern and Central parts of Europe. NH_3 is not a key issue in the legislation in the US.[17]

---

[17] Efforts have been made during this project to determine concretely why ammonia emissions are more of an issue in the EU than in the US. No policy documents were found in the US outlining the rationale. The issue is likely to be more of a state-by-state issue and thus relevant control efforts would be found in state documents which were outside the scope of this project.

- Progress has been made in reducing ground level ozone formation in both regions; however, ozone formation is still a problem in many parts of the two regions.

- Technological innovation has occurred to some extent in both regions over the studied period. Some analysis has found that this is a result of the choice of environmental policy in the respective locations. Further analysis targeted at this particular issue may yield greater insight on the impact of these policies on technological innovation.

- Analysis in both Europe and the US have found that the benefits (in economic valuation) have outweighed the costs of a number of air quality controls. For example, the total cost of reaching the emission ceilings is expected to be about 70 billion euros (US$ 75 billion) a year, compared with the benefits estimated at roughly 200 billion euros (US$ 214 billion) a year. Likewise, the annual benefits of the US Acid Rain SO_2 regulations ($78 to $79 billion dollars) far exceeded the costs ($1 to $2 billion dollars) during the early years of the acid rain trading program.

- A recent analysis found that environmental controls in Europe had not placed European industries at a competitive disadvantage vis a vis operations in other countries. A similar analysis was not available to compare competitiveness issues in the US.

- The transparent system of the US Acid Rain Program in which non-compliance and penalties are well understood led to a near-perfect record of compliance. Because all participating units must have working CEMs, there is no question as to the number of allowances that are needed for compliance. It became less expensive for firms to comply with the requirements than to avoid compliance by seeking the various forms of modifications that characterize traditional regulatory programs in the US such as exemptions, exceptions, or relaxations of the program’s requirements.

- In theory, emissions trading programs such as the US SO_2 provisions under Title IV require greater up-front design efforts versus command-and-control approaches, but a smaller government role in implementation. In addition, the required administrative tasks differ across the two approaches. Instead of the inspection and enforcement role that is typical under a command-and-control regime, under cap-and-trade, the government role largely shifts to ensuring that CEMs are in working order and managing the data. Actual costs to EPA to implement the Acid Rain Program during the five years following the Clean Air Act Amendments came to $44 million, or 4 percent of total costs to implement the Clean Air Act in the same period.

CASE STUDY 1 – ANNEX I

ACIDIFICATION, EUROPHICATION AND GROUND LEVEL OZONE

4 October 2004

1. INTRODUCTION

The acidification, eutrophication (nitrogen deposition) and ground level ozone problems are mainly air pollution problems in a regional scale and the pollutants involved are especially NO_x (mainly NO and NO_2), SO_2, NH_3 and VOCs. However, some of the pollutants can also give rise to air pollution problems in the local scale, e.g. NH_3, NO_2, SO_2 and some VOCs.
Acidification and eutrophication are air pollution problems, which are closely connected, because the pollutants and sources to a large extend are the same. Eutrophication and ground level ozone are also closely related due to common pollutant sources.

2. ACIDIFICATION AND EUTROPHICATION

2.1. Formation and transport of acidifying and eutrophying substances

Acidifying and eutrophying pollutants originate primarily from anthropogenic emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3). Most of SO_2 and NO_x is emitted to the atmosphere from combustion of fossil fuel in power plants, industrial plants, residential heating, commercial and service sectors. Road transport, shipping and aircraft are significant sources of NO_x emissions. NH_3 emissions are related to agricultural activities such as storage of manure, soil fertilising, animal husbandry, etc.
Parts of the SO_2 and NO_x will be oxidised to sulphate and nitrate compounds. The man-made gaseous sulphur and nitrogen compound emissions are precursors to the formation of fine particles ($PM_{2.5}$). NH_3 is often present in sufficient concentrations to form ammonium nitrate and ammonium sulphate particles. The acidifying and eutrophying air pollutants - gases and especially fine particles - may remain in air for several days and therefore be dispersed and transported over long distances, e.g. thousands of kilometres. They can be transported across national/state boundaries and cause damaging effects far away from the sources. Acidifying and eutrophying pollutants are removed from the atmosphere by wet deposition (e.g. "acid rain") or dry deposition (direct deposition and uptake on vegetation and surfaces).

2.2. Environmental impact

2.2.1. Effects on ecosystems

The effects of acid deposition are widespread and appear in many ways, including e.g. acidification of freshwater systems resulting in the loss of fisheries, impoverishment of soils, damages to forests and vegetation, corrosion of buildings, cultural monuments and materials. The consequences of the deposition of acidifying substances include changes in the mineral balance in soils as nutrients are leached through increasing acidity, and changed water chemistry directly and as a consequence of soil leaching. The combination of greater acidity with increased mineral content can be toxic to aquatic life, whilst loss of nutrients and greater soil toxicity can affect vegetation.

Deposition of nitrogen compounds also contributes to the eutrophication ("excess nutrient enrichment") of terrestrial and marine ecosystems. Thus excess deposition of nitrogen compounds may enhance growth. This begins as a minor, or even desirable, effect but soon reaches a point where disturbance to ecological systems becomes detrimental. This process is known as eutrophication. As well as affecting terrestrial and freshwater ecosystems, coastal waters and shallow regional seas can also undergo eutrophication, contributing e.g. to algae blooming. The eutrophying effect is associated with increased leaching of nitrogen compounds to ground water, streams, lakes and coast near seas and changes in forest ecosystems leading to vegetation changes favouring nitrogen-tolerant species. Manuring and fertilisation in the agriculture as well as urban wastewater discharges are important sources and should be controlled at the same time. Appropriate control is at the watershed level and the ideal balance of controls may differ from one watershed to another.

Soils and waters will have a natural capacity to absorb a certain quantity of potentially polluting deposition termed ***the critical load***. If these critical loads are exceeded, significant harm may be anticipated. For acidifying deposition load capacity is required for buffering the received acidity; for eutrophication it is the capacity to utilise and to immobilise nitrogen. The issue is exceedence of these capacities.

2.2.2. Health effects

The gases involved in formation of acidifying and eutrophying substances cause especially local health effects. Moreover, the particles formed from these substances contribute significantly to the particle exposure of the population with PM_{10} and especially fine particles, $PM_{2.5}$. These particles are normally assumed to cause health effects like all other fine particles, but this effect is still not documented.

2.2.3. Effects on material

Atmospheric corrosion/deterioration of materials is a cumulative, irreversible process that takes place under all climatic conditions. Acidifying air pollutants will increase the rate of the deterioration processes. The corrosion can be explained by two main reaction mechanisms. Close to the emission sources the direct effect of sulphur dioxide dominates ('dry' corrosion) while the effect of the acid part is more important in background areas ('wet' corrosion).

Sulphur dioxide and the further oxidised sulphuric acid are known to have a strong effect on the processes. However, laboratory tests show that a mixture of gases like nitrogen dioxide and ozone will increase the deterioration rates for materials. Also a mixture of other gases will contribute to natural corrosion. In terms of dose-response the dominating explanatory factors are sulphur dioxide and acid rain. Current findings indicate that only copper has a dose-response equation containing both sulphur dioxide and ozone concentrations. Since most of the material objects are in urban and industrial areas where most of the emissions exist, the highest deterioration rates and greatest impacts will occur there.

3. GROUND LEVEL OZONE

3.1. Formation transport of ozone

A number of man-made pollutants, such as nitrogen oxides (NO_x) and volatile organic compounds (VOC) cause photochemical activity in atmosphere. Nitrogen oxides are emitted mainly from combustion processes from both mobile sources (e.g. road traffic) and stationary sources (e.g. power plants). VOC are emitted from combustion and also by evaporation of fuels and solvents. Furthermore natural emissions, in particular hydrocarbons from vegetation, will also contribute to the photochemical activity.

The photochemical activity leads to production of other toxic pollutants - mainly ozone. The production of ozone requires sunlight. The ozone is mainly a problem in the summer months. The emissions of ozone precursors have increased the ground level ozone in the Northern Hemisphere to levels three to four times those of pre-industrial era.

Episodes with high levels of ozone occur mainly during summer, and especially in the southern parts of Europe and the USA and where the emissions of precursors are high. To avoid such pollution events emissions must be reduced. However the chemical mechanisms involved are complicated and there are still uncertainties as to how reductions should be made cost effective. In particular, reductions are desirable for nitrogen oxides due to other environmental reasons also, such as acidification and eutrophication.

3.2. Health effects and environmental impact

Ozone causes serious health problems and damage to materials and ecosystems. Ground level ozone in both Europe and North America affects lung function, particularly in children and asthmatics, either from short-term exposure to high ozone levels or from longer-term exposure to lower levels. Ozone also causes leaf injury in plants, including crops and trees, significantly reducing plant growth and crop yield, and causes some materials – particularly organic materials such as paint and rubber – to disintegrate.

Human exposure to elevated levels of ozone concentrations can give rise to inflammatory responses and decreases in lung function. Symptoms observed are cough, chest pain, difficulty in breathing, headache and eye irritation. Both laboratory and epidemiological data indicate large variations between individuals in response to episodic ozone exposure. The effects seem to be more pronounced in children than in adults. Studies indicate that exposure to ozone concentrations in the range 160-360 mg/m3 for a period of 1-8 hours - concentrations often observed in ambient air over Europe - reduces various pulmonary functions.

Ozone exposure of ecosystems and agricultural crops results in visible foliar injury and in reductions in crop yield and seed production. For vegetation a long-term, growing season- averaged exposure rather than an episodic exposure is of concern. Adverse effects on vegetation can be noted at relatively low ozone levels. Within the framework of the UN-ECE Convention on Long-Range Transboundary Air Pollution the critical level for ozone is expressed as the accumulated ozone exposure above a threshold of 40 ppb (corresponding with 80 mg/m3).

It is known that ozone affects materials such as natural and synthetic rubbers, coatings and textiles. However, there are today serious gaps in knowledge on the mechanisms of damage, the attribution of ozone to damage in comparison to other factors and the economic evaluation of such damage. As far as is understood, there is no "no-effect level" of ozone for material corrosion; it is assumed that dose-response relations for materials are linear or nearly linear under ambient conditions. Recently, synergistic effects of ozone in combination with the acidifying components SO_2 and NO_2 have been reported to lead to increased corrosion on building materials like steel, zinc, copper, aluminium and bronze.

Ozone in the troposphere is also of relevance to climate change since ozone is a greenhouse gas. It is currently estimated that tropospheric ozone adds 0.35 W.m-2 to the current enhanced climate forcing of 2.45 W.m-2 by long-lived greenhouse gases.

CASE STUDY 1 – ANNEX II

THE EU APPROACH TOWARDS ACIDIFICATION, EUTROPHICATION AND GROUND LEVEL OZONE

4 October 2004

1. ACIDIFICATION AND EUTROPHICATION

1.1. Introduction

The observed acid rain damages in the early 1970s led to the conclusion among scientists and policy-makers that air pollution was an international problem due to long range transport of pollutants like SO_2 and NO_x. Particular blame was placed on emissions from fossil-fuelled power stations and other large combustion plants. The two major polluters, UK and Germany, initially refused to accept that their industrial activities were linked to the acidification damages in neighbour countries, especially the Scandinavian countries. However, the forest death alarm changed Germany's position drastically, and the German Government issued the Large Combustion Plant Ordinance. In order to avoid competitive disadvantages for Germany's industries, Germany argued for similar measures in other Member States. The Netherlands and Denmark, who have a similar regulatory tradition as Germany, supported the German attempt to upload its policies to the European level.

The Commission followed up with a proposal of the Industrial Plant Directive (84/360/EC) in April 1983. The Directive was in accordance with the UK approach of weighing the economic costs against the environmental benefits by replacing the German concept of "state of the art" by "the best available technology not entailing excessive costs" (BATNEEC). The UK then also accepted the Industrial Plant Directive.

Additional measures to promote the reduction of the pollutants included in the CLRTAP and the European legislation have now been implemented in many countries. In addition, political pressures played a big role in prodding some countries to take even more stringent measures. Examples are requirements on sulphur content in fuel used in large combustion plants and introduction of measures earlier than required by EU emission limits for stationary sources (sulphur scrubbers or low-NO_x burners) and mobile sources (three way catalysts), especially in the Nordic countries and Germany.
The Nordic countries and some other countries have used economic incentives to promote the reduction measures, especially in relation to energy and process industries, e.g. tax on SO_2 and NO_x, but also local requirements on low sulphur content in fuel, e.g. in specific areas/urban areas, and emission standards for new vehicles.

1.2. Emissions Sources

Acidification, eutrophication (nitrogen deposition) and ground level ozone problems are mainly air pollution problems in a regional scale and the pollutants involved are especially NO_x (mainly NO and NO_2), SO_2, NH_3 and VOCs. However, some of the pollutants can also give rise to air pollution problems in the local scale, e.g. NH_3, NO_2, SO_2 and some VOCs.

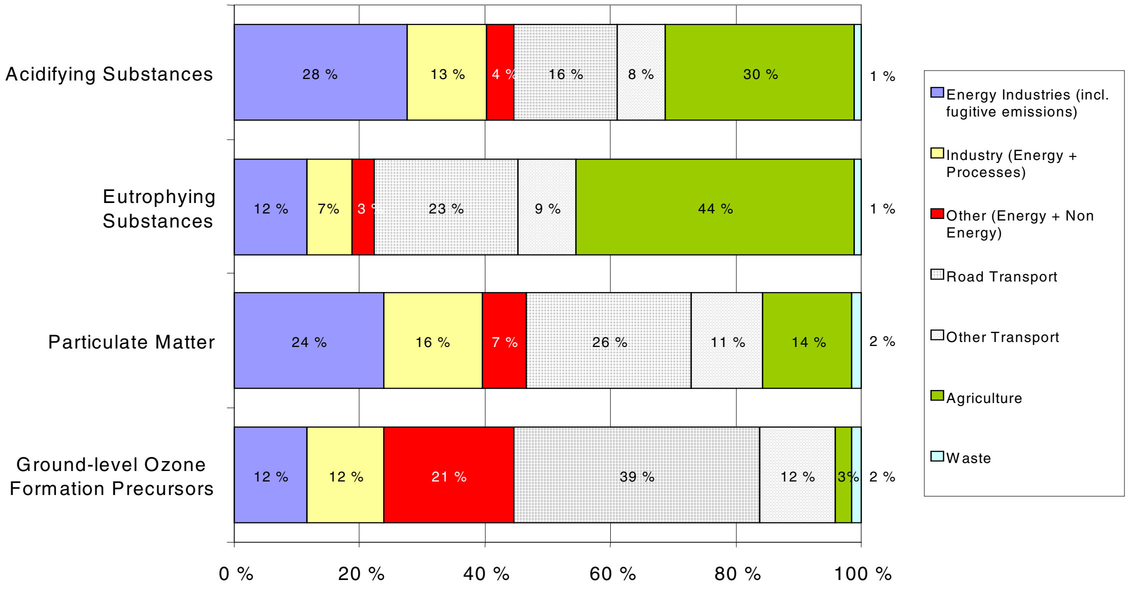
Acidification and eutrophication are air pollution problems which are closely connected because the pollutants and sources to a large extent are the same. Eutrophication and ground level ozone are also closely related due to common pollutant sources.

The total emissions of acidifying, eutrophying and ozone formation precursor pollutants from the main sectors in the EEA[18] countries and accession countries are shown in *Figure 8*.

---

[18] European Environmental Agency, http://www.eea.eu.int/main_html

(a) EEA-18 countries



(b) AC-13 countries

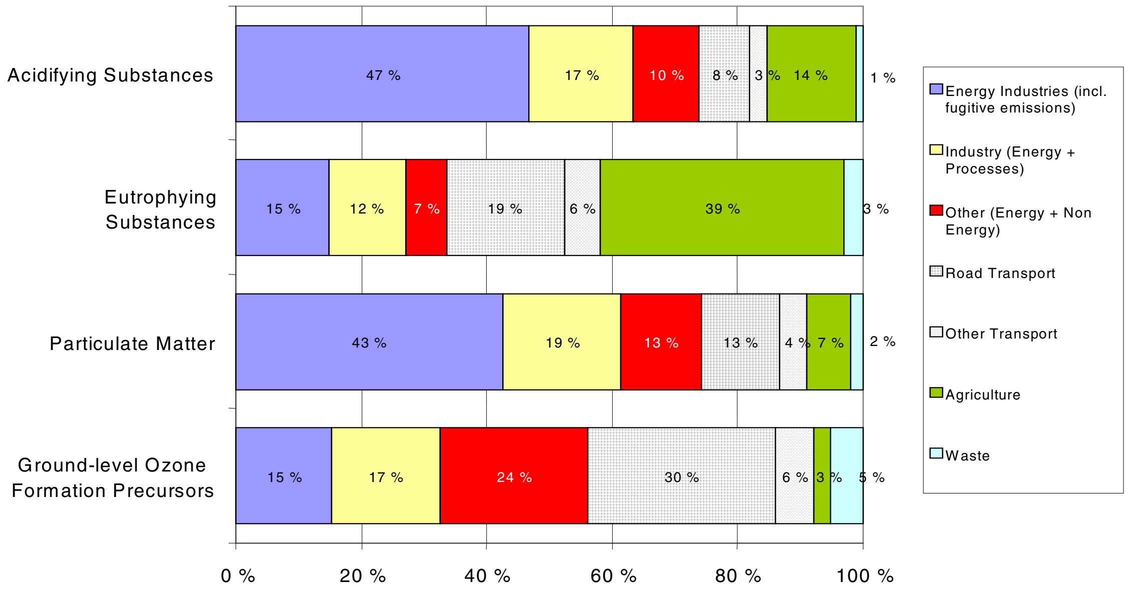


Figure 8 Sector contributions to selected air pollution issues in 2000 (EEA, 2003c). Acidifying substances are SO_2, NO_x and NH_3. Eutrophying substances are NO_x and NH_3. Ground level ozone formation precursors are NO_x and VOCs. Methodologies used to aggregate pollutants contributing to acidification, eutrophication and particulate matter are described in the respective Air Pollution fact sheets (EEA, 2003).

1.3. Legislation and measures implemented

The European legislation and other types of agreements affecting acidification and eutrophication are mainly the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and its Protocols, the EU directives and different national laws.

1.3.1. The Convention on Long-range Transboundary Air Pollution

Sulphur emissions in Europe started to increase after the Second World War. Acid precipitation, acidification and the subsequently serious damages on life in lakes and rivers were observed around 1970 in the Scandinavian countries. This was reported at the UN Stockholm Conference in 1972. The problem of transboundary air pollution – of not only sulphur, but also other pollutants - was put on the political agenda (UNECE, 1999).

With reference to the declaration of the 1972 UN Conference on the Human Environment in Stockholm, to the effect that states have an obligation to ensure that activities carried out in one country do not give rise to environmental damage in others, the Scandinavian countries jointly presented a draft for a convention. The then 35 members of the UNECE, including the European Community signed the Convention on Long-range Transboundary Air Pollution (CLRTAP) in Geneva in 1979. After ratification by 24 of the signatories, it came into force in March 1983. As of 2003, 49 countries have signed. The Convention does not in itself call for any binding commitments to undertake concrete measures for the reduction of specific pollutants. The text only says that countries shall ”endeavour to limit and, as far as possible, gradually reduce and prevent air pollution,” and that, in order to achieve this, they shall use ”the best available technology which is economically feasible.”
The Convention was the first international legally binding instrument to deal with problems of air pollution on a broad regional basis. In addition to the general principles of international co-operation for air pollution abatement, the Convention sets up an institutional framework bringing together research and policy.

For example, since 1977 the monitoring of transboundary air pollution has been carried out under the European Monitoring and Evaluation Programme (EMEP). The EMEP network now comprises some 100 monitoring stations in more than 25 countries. The EMEP collates data on the national emissions of sulphur and nitrogen (ammonia and nitrogen oxides), as well as data on transformation and transport in the atmosphere and deposition. The parties of the Convention took over the long-term financing of EMEP in 1984.

The Convention has been extended by specific protocols, five of which are significant for addressing acidification and eutrophication:

- The 1985 Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent (entered into force 1987).
- The 1988 Protocol concerning the Control of Nitrogen Oxides or their Transboundary Fluxes (entered into force 1991).
- The 1991 Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes (entered into force 1997).
- The 1994 Protocol on Further Reduction of Sulphur Emissions (entered into force 1998).
- The 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (not yet in force).

The Convention has helped generate data. It has moreover promoted the exchange of knowledge and experience and influenced the decisions of various countries with regard to their measures for reduction of emissions. The process has put pressure from public opinion to get a protocol signed and respected.

1.3.2. The First Sulphur Protocol

In the spring of 1983 the Scandinavian countries put forward a proposal for limiting the emissions of sulphur. After two years of negotiating, a protocol was signed in Helsinki, Finland, in 1985. and it came into force in September 1987. It requires the signatories to reduce their national yearly emissions of sulphur, or its transboundary fluxes, by at least 30 per cent by 1993 at the latest, from their 1980 levels. The 30-per-cent criterion was to be regarded as the first step in a long-term project for reducing emissions. Some of the greatest polluters, such as Poland, Britain, and Spain, did not sign the protocol. Between 1980 and 1993, the 20 European countries which ratified the protocol reduced their annual emissions by 55 per cent, while total European emissions of sulphur dropped by 43 per cent, (EMEP data).

1.3.3. The critical loads approach

In 1988, the Convention appointed a new working group to develop a common critical-loads approach and to evolve abatement strategies based on that approach. The essence of the critical loads approach is that reductions of emissions are to be negotiated with a view to the effects of air pollutants, rather than by setting an equal percentage of reduction for all countries. The aim is to reduce, in a cost-effective manner, the emissions of air pollutants to levels where the critical loads will not be exceeded. This concept provided an acceptable, effects-based scientific approach for strategies for the abatement of air pollution. Each country was to make maps, showing the critical loads and levels for various areas, receptors, and pollutants in its own territory. The resulting data was assembled into Europe-wide maps showing exceedances of the critical loads and level. Computer models for integrated assessment enabled comparisons to be made of the cost-effectiveness of various strategies for achieving specified interim targets for environmental quality and the protection of health. Agreements were then reached on the reduction of emissions (interim targets) strategies for the abatement of emissions, and the reductions to be allocated among the various countries in the form of national ceilings for emissions.

1.3.4. The Second Sulphur Protocol

The first result of the critical loads approach was the 1994 Second Sulphur Protocol, which came into Force in 1988. It sets differing requirements for each country – the aim being to attain the greatest possible effect for the environment at the least overall cost. It also includes some specific requirements for large combustion plants. The text for basic obligations says that "parties shall control and reduce their sulphur emissions in order to protect human health and the environment from adverse effects," and ensure that sulphur depositions do not, in the long term, exceed critical loads. The scientific analysis of the protocol showed that in order to comply with the long-term goal was to be attained; the emissions of sulphur should be reduced by at least 90 per cent. The countries commit under the protocol to reduce total European emissions of sulphur by 50 per cent by 2000, and 58 per cent by 2010, in relation to the level in 1980.

1.3.5. The NO_x Protocol

In the meantime eutrophication was observed on sensitive ecosystems, e.g. raised bogs, moors, lakes and coasts-near seas. In addition, ground-level ozone was now realised as an environmental problem in relation to health as well as damages on vegetation. NO_x plays an important role in both cases.

The 1988, Protocol on the control of nitrogen oxides, which came into force in 1991, provides that emissions after 1994 should not exceed the 1987 level. It does not call for reduction, but defines the basis for a next step involving measures to reduce emissions, taking into account internationally accepted critical loads. Twelve signatories pointed out the weakness of this protocol by proposing separately, in a joint declaration, to reduce their NO_x emissions by 30 per cent by 1998 at the latest. By 1994 the European emissions were reduced by about 16 per cent in relation to the 1987 levels. From the reported emission data it appeared however that three countries that had ratified the Protocol – Greece, Luxembourg, and Spain – had not managed even to freeze emissions. And of the 12 that were aiming at a 30 per cent reduction, only four or five had succeeded.

1.3.6. The Gothenburg protocol

The 1999 Gothenburg, Protocol aims at significant reduction of acidification, eutrophication, and the formation of ground-level ozone by setting national ceilings for emissions of the four pollutants that give rise to these effects, namely SO2, NO_x, VOCs, and ammonia. Starting from the critical loads approach and by attacking several environmental problems and several pollutants simultaneously in a co-ordinated manner, the overall level of cost-effectiveness could be improved even further. The

Protocol also contains binding requirements in the form of emission limit values both for stationary and mobile sources, as well as fuel standards. The European emissions of SO_2, NO_x, VOCs, and NH_3 are expected to decrease by respectively 63, 40, 40, and 17 per cent between 1990 and 2010. In order to attain the internationally agreed long-term aim of no more exceeding of the critical loads, a stepwise approach involving reviews of this protocol is foreseen. The Protocol is not yet in force.

1.3.7. The EU legislation

Up to the early 1990s, the EU policy in relation to acidification, eutrophication and ground level ozone has focussed on directives setting air-quality standards for a few selected air pollutants. The pollutants were first of all sulphur dioxide and nitrogen oxides. Other Directives aimed to control emissions from certain defined sources such as large power plants and road vehicles.

The Fifth Environmental Action Programme, presented in 1992, contained proposals for long-term environmental objectives both for air quality and acidification. It stated that "all people should be effectively protected against recognised health risks from air pollution," and that "permitted concentration levels of air pollutants should take into account the protection of the environment." For the acidifying, eutrophying, and ozone-forming pollutants – sulphur dioxide, nitrogen oxides, volatile organic compounds, and ammonia – the aim was that "no exceeding ever of critical loads and levels" should take place.

The Auto-Oil program I started in 1992, aimed at setting new environmental requirements for road vehicles (cars, trucks, and buses) and fuels. The requirements were to match certain defined aims for air quality so as to comply with the World Health Organisation guidelines to be cost-effectively attained by 2010. The program, which was concluded in 1996, resulted in several new directives being adopted in the following years. In the mid 1990s the Framework Directive on Air Quality was adopted as well as a completely new Directive for the integrated prevention and control of pollution (IPPC). The Framework Directive on Air Quality provided the basis for various Daughter Directives setting limits to the concentrations of several separate air pollutants. A list of directives is given in the database.

The EU legislation was influenced by the Convention on Long Range Transboundary Air Pollution. The Commission in March 1997 presented a strategy for abatement of acidification within the Community, which included clearly defined environmental targets to be attained as cost-effectively as possible by 2010. The EU acidification strategy involves a revision and tightening up of two important directives: the one for controlling the sulphur content of liquid fuels and the other on emissions of SO_2, NO_x, and particles from large combustion plants. The acidification strategy was later followed up by requirement on reduction of the concentrations of ground-level ozone. These laid the foundation for a Commission proposal for a Directive setting binding national ceilings for the emissions of four acidifying and ozone-forming air pollutants, which was formally adopted in 2001.

The EU directives affecting emissions and concentrations of air pollutants establish:

National emission ceilings for acidifying and ozone-forming air pollutants (2001/81/EC).
The directive sets binding ceilings to be attained by each Member State by 2010, and covers four air pollutants: SO_2, NO_x, VOC_s, and NH_3. MS total emissions of these four pollutants are to be reduced by 77, 51, 54, and 14 per cent respectively between 1990 and 2010. The NEC Directive is scheduled for review and revision in 2004, when it is expected that proposals will be made to extend it to small particles and to set new ceilings.

Control of emissions from large combustion plants (2001/80/EC).
This covers plants with a rated thermal capacity of at least 50 MW and replaces the existing Directive of 1988 (88/609/EC), which was the Daughter Directive of the Industrial Plant Directive (84/360/EC). It contains emission limits for SO_2, NO_x, and dust, varying according to the age and capacity of the plants, as well as the type of fuel burned. It tightens up the requirements for new plants, and introduces

for the first time emission limits for existing ones. In 2004-2005 review and possible revision are expected.

Sulphur content of certain liquid fuels (99/32/EC)
This sets the maximum permitted concentration for sulphur in heavy fuel oil used in the EU at 1 per cent as from 2003, and for gas oils at 0.2 per cent, to be reduced to 0.1 per cent from 2008. Discussions are proceeding on a possible revision in order to include bunker fuel (heavy fuel oil used in ships).

Quality of petrol and diesel fuels (98/70/EC)
The Directive prescribes among other things 350 and 150 ppm as maximum sulphur content for diesel and petrol respectively. From 2005 the figure will be lowered to in both cases 50 ppm (0.005 per cent). A proposal to lower it even further, to 10 ppm by 2010, is under consideration.

Emissions of air pollutants from road vehicles.
Three Directives address mainly the emissions of NO_x, non-methane VOC_s, and small particles. The Directive for passenger cars and light commercial vehicles (98/69/EC) specifies emission standards to be introduced in two steps - the first in 2000 and the second in 2005. Directive 99/96/EC takes a similar stepwise approach for heavy vehicles, but with the inclusion of a third step (for 2008). Directive 97/24/EC sets emission standards for two and three-wheeled vehicles, mopeds and motorcycles. An amendment with stricter standards for motorcycles was agreed in March 2002.

Framework Directive on ambient air quality assessment and management (96/62/EC).
The Framework Directive provides the basis for setting limit values to the concentrations of pollutants in the air by preparation of Daughter Directives. The first (99/30/EC) sets standards for SO_2, NO_x, particulates (PM10), and lead. The second (2000/69/EC) covers carbon monoxide and benzene while the third deals with ground-level ozone (2002/3/EC). A proposal for a fourth Daughter Directive covering polyaromatic hydrocarbons (PAH) and three heavy metals (nickel, cadmium, and arsenic) is expected to be approved in 2004. Review and revision of the first daughter directive is foreseen to take place in 2004.

Integrated pollution prevention and control (96/61/EC)
The IPPC Directive aims at preventing or reducing pollution of air, water and land through a comprehensive system of permits. It applies to a significant number of activities, mainly industrial. Since the end of 1999 new installations are required to have a permit issued in compliance with the Directive, which means they are expected to employ best available techniques (BAT). Existing plants are expected to comply by 2007. Guidance to BAT for various sectors of industry is given in reference documents (BREFs).

In addition to the EU directives that directly affect emissions and concentrations of air pollutants, a number of directives and other actions at EU level can have indirect effect, e.g. those aimed at reducing the emissions of greenhouse gases and others capable of influencing developments in the energy, transportation, and agricultural sectors. Some of these directives are quite new and have not yet had influence on the air quality, but aims at improvement within the next decade.

1.3.8. National legislation

The EU legislation had to be transposed to national law and the CLRTAP was also – with a few exceptions for specific protocols - followed up by national rules and regulations of different types, e.g. strict regulations of specific pollution sources, developed permit systems, fuel requirements, obligatory tax and economic incentives. However, not all European countries have made sufficient effective national rules and regulations.

1.3.9. CAFÉ

The more strategically oriented work on air quality that was set going in the 1990s was followed up by a new program under the name of CAFE, Clean Air For Europe, presented by the Commission in 2001. The CAFE program will deal mainly with particles and ground-level ozone, both because of their serious effects on health, and the big challenge to bring down the concentrations to a safe level. However, acidification and eutrophication will also be on the agenda, and a focus will be on trends of pollutants that are unregulated, as well as “hot spot” areas with high levels of pollution.

1.3.10. Economic incentives in select Member States

Environmental taxation and emissions trading programmes have been developed some time ago. However, it is only over the last decade that such schemes have been practically implemented in practice. The taxation of environmental pollutants has become increasing prevalent in OECD countries, where it has gained popularity both as an alternative to command and control regulation, but also as an alternative revenue raiser to more traditional taxes (e.g. away from labour taxes). Market based emission trading schemes are also growing in popularity, driven by their success in the US.

1.3.10.1. Emissions Trading

Klaassen (1997) provided a comprehensive review of the potential for the instrument in the European Union, and the UK and Denmark moved ahead to implement a trading scheme directed at greenhouse gasses. The EU is now well along in the process of establishing a community – wide GHG emissions trading scheme.

A number of European Countries are piloting emissions trading schemes for air pollutants. For example, the Netherlands is implementing a national acid precursor emissions trading scheme that is rate based only, even though the country faces an absolute cap on such emissions under the NEC Directive.

The design principles of the Dutch trading regime is based on a dynamic cap (performance standard rate, PSR), which appeared to fit into the current environmental policies and legislation and is supported by industry (ENAP, 2002). The regime sets a 55 ktonnes target for 2010 and uses a decreasing PSR up to 2010 (65 grammes per GJ in 2004 to 50 grams per GJ in 2010), with an evaluation and possible adjustment in 2005. The limits imposed on the Dutch regime under EU legislation require the regime to be implemented parallel to existing EU legislation. The difficulties with using installation-specific emissions limit values (ELV_s) to achieve the Dutch NO_x target for industry for 2010 derived from the obligations under the NEC Directive. The difficulties in negotiating ELV_s, the slower than expected innovations in and replacement of installations and the greatly differing possibilities of emission reductions between installations, resulted in the Netherlands only being halfway its target in 2000. The advantages of emissions trading for industrial emission sources are expected to allow the Netherlands’ regime to reach targets that cannot be reached through traditional regulatory mechanisms.

A Trading Scheme to Reduce Emissions of Sulphur Dioxide and Nitrogen Oxides from Point Source Combustion Processes has also been proposed for the UK (ENAP, 2002). The proposals for a UK trading scheme were still under discussion in the UK regarding how ET could address the environmental challenges of reducing SO_2 and NO_x. The scheme could focus on emissions from installations, but would not cover road transport which contributes 50% of UK NO_x emissions. Currently the strategy for controlling SO_2 and NO_x from coal and oil fired power stations uses the IPC (Integrated Pollution Control) approach. It is still being debated whether a focus on technology standards approach or ET will be chosen in the UK. If an ET scheme, then it will build on the current A and B limits, with trading allowed with regard to the B cap, and no trading on A limits allowed. In other words, industry will be able to choose which technologies/techniques are needed and where, in order to meet the Cap, and this “choice” would be delivered through IPPC permits. The IPPC permits would note the site specific techniques/technologies as well as note the ET context and conditions. The scheme would apply to large combustion plants, and the key feature is a sector based approach (look at performance currently, costs and then arrive at reduction strategy from that), supplemented by site specific requirements.

1.3.10.2. Application of economic incentives in Sweden and France

A comparative study of application of economic instruments was performed recently for Sweden and France (Millock and Sterner, 2004). Both countries have charges (or taxes) as supplementary instruments to command and control for control NO_x emissions from energy sector and industry boilers. Both systems build on pre-existing command-and-control legislation, and at least in the French case they aim to complement rather than substitute this legislation.

The Swedish program dates back to 1992. The revenues from the Swedish charge are automatically recycled through payments to industry based on the energy produced. The Swedish tax was due primarily to concern over acid rain and introduced as a specific policy tool to accelerate the reduction of NO_x emissions from the industry sector. The term Refunded Emission Payment (REP) is used for the program, since the Swedish Environmental Protection Agency (SEPA) returns the money to the firms. SEPA covers its administrative costs from the fees collected but they amount to only half of one percent of revenues.

France has a tax applied to four different categories of air pollution, which in some respects is a little similar but at a much smaller level and with different criteria for refunding of the tax revenues. The origin of the French tax system goes back to the mid 1980s and the debate on acid rain. The majority of the funds collected by the French tax are used to subsidise abatement investments among the firms that emit NO_x, but there is no automatic mechanism for the return of funds. Rather, firms are free to apply for subsidies to finance abatement investments. The difference between the two programs is small.

The Swedish program. In relation to the Swedish acid rain program Sweden has introduced a tax of 3000 $/tonne, which led to dramatic reductions for NO_x .The ambitions were high in relation to acid rain, but also in order to reduce eutrophication of lakes, rivers and coastal areas. (Ground level ozone is of less concern in Sweden). However, the emission reductions of NO_x were found to be much more difficult, because the reduction processes/possibilities are more difficult to apply. Although the traffic sector is an important source of NO_x emissions, additional reductions were necessary from energy production and industry sectors for the objective to be met.

The Swedish charge covers NO_x emissions from all industrial boilers, stationary combustion engines and gas turbines with a useful energy production of at least 40 GWh and in 1997 the limit was lowered to 25 GWh of useful energy per year. Today about 250 plants (375 boilers) are subject to the law emitting about 14 000 tonnes of NO_x a year, which represents approximately 5 % of the total NO_x emissions in Sweden. The SEPA manages the scheme at a small administrative cost amounting to 0.2–0.3% of revenues. The entire remaining revenue of over 50 million $ per year is refunded in proportion to output of useful energy. “Useful energy” produced has been accepted as the metric when comparing paper mills, power plants, and other heterogeneous activities that use large boilers, engines or gas turbines. For power plants and district heating plants it is equal to the energy sold. For other industries, the energy is defined as steam, hot water or electricity produced in the boiler and used in production processes or heating of factory buildings. The tax rate is 4 $ per kg NO_x. The charge is based either on actually monitored emissions, or other accepted data. The refund varies from year to year, but in recent years it has been just under 1 $ MWh useful energy. This implies that the average emission factor has been about 0.25 kg NO_x/MWh. *Table 7* shows the progress of the Swedish program.

Table 7. Summary statistics regarding combustion plants subject to the Swedish NO_x charge 1992-2000 (Millock & Sterner, 2004).

Year	Number of production units (combustion plants)	NO_x emissions (tons)	Produced energy	kg NO_x / MWh produced energy	Charges levied (and refunded) SEK (million)
1992	181	15305	37465	0.41	612
1993	189	13333	41158	0.32	533
1994	202	13025	45193	0.29	521
1995	210	12517	46627	0.27	501
1996	274	16083	57150	0.28	643
1997	371	15107	54911	0.28	604
1998	374	14617	56367	0.26	585
1999	375	12827	48956	0.26	513
2000	363	12644	51073	0.25	506

The French program. The French tax is administered by the Agency for Environment and Energy Management (ADEME). It applied to all units with a power capacity of at least 20 MW. The French tax covered a large number of sources (from 1200 in 1990 to nearly 1500 in 1999), but the level of the French tax was only about 1% of the Swedish one (between 30 $/tonne and 50 $/tonne). The French tax revenues were recycled through subsidies for abatement measures. ADEME received 6% of total tax revenues to cover its administration costs, but 75% of the tax revenues were used for abatement subsidies, with the rest being allocated to the financing of air pollution surveillance systems. Any company subject to the TPPA could apply for a subsidy which was awarded according to percentage rates of the additional fixed capital investment for emissions reduction: 15% for standard abatement technologies, 30% for particularly innovative technologies. There was also an additional 10% subsidy to small and medium-sized companies. A few rejections of subsidy requests concerned plants for which the abatement objectives were not considered ambitious enough, in the sense that the investment aimed at fulfilling a French decree or a European Union directive whose implementation date already had passed.

The French program led to an estimated reduction of 27,000 tonnes of NO_x per year. The abatement investments were 3,500 - 8,000 millions $ per year in the years 1995-1997, and the benefit was estimated to around 1000 $/tonnes NO_x

Comparison of the two programs. The comparative study (Millock and Sterner, 2004) concluded i.e., the following.

Both the Swedish and the French tax schemes aimed at limiting the regulatory burden on firms by imposing a threshold level for taxation. In the Swedish case, this limit was consequently reduced downwards to encompass more units as the policy proved effective. The low level of the French tax implied less economic efficiency. Rather than driving technical development, the French tax on NO_x emissions can be regarded as a complementary policy instrument to give firms additional incentives to implement command-and-control regulation in a timelier manner.

The Swedish NO_x charge has implied a strong incentive both for fuel switching, modifications to combustion engineering and the installation of specific abatement equipment such as catalytic converters and selective non-catalytic reduction. The Swedish NO_x charge has also implied a strong incentive to use the equipment, and to fine tune combustion and other processes in such a way as to minimise emissions. According to Swedish experience there is a strong connection between actual monitoring and emission reductions by fine-tuning. The monitoring became a reality due to the high charges that had to be based on accurate emission figures.

The administrative costs of the tax instrument were low in both cases. In the French case, administration costs were allocated a fixed percentage rate of total tax revenues (6%) and in the Swedish case, the SEPA estimates the central administrative costs to approximately 0.6% of total yearly tax revenues. Monitoring requirements are an order of magnitude higher. In the French case, however, monitoring relied to a large extent on existing regulatory structures for control of standards-based regulation. The French tax revenues were also used partly to finance investment in better monitoring of air pollution.

The environmental efficiency of the French tax was probably low. However, an advantage with the French tax was that it allowed for government and regulatory agencies to collect and improve information on emission levels and abatement actions undertaken by firms in different industry sectors. In this sense, it yielded a distinct advantage to government compared to the existing command and control regulation.

One of the important effects of having really high levels of payments as in the Swedish program is that the emissions become more visible to management and to regulators. In this particular case, one of the main results of the Swedish program is that emissions of NO_x vary strongly with fine-tuning of plant operations. Detailed monitoring is the only way such fine-tuning can actually be undertaken since it is the only way plant engineers themselves will realise the effects of various small changes in temperature and other combustion conditions. Detailed monitoring is thus crucial. In this respect, there is a drawback with the French scheme, with its flexibility in the use of real monitoring versus emission factors. In the Swedish program with a very high fee level has been the only one that has led to the common adoption of sophisticated and detailed monitoring. The other positive effect of a high fee is that it makes a number of quite sophisticated pieces of abatement equipment profitable. This also is an important effect which may however partly be achieved through other instruments such as subsidies to abatement or through an emissions trading program as long as the price of permits is sufficiently high. The disadvantage of having a refunded charge rather than a tax is that the output and revenue raising effects of a tax are lost. The considerable advantage of the REP is that it makes a high charge level politically feasible. Thus this instrument is promising for situations in which the technical abatement possibilities are abundant but fairly expensive and where the output and revenue raising effects are less important.

1.3.11. The German policy to reduce SO_2 emissions from large combustion plants.

The decline of forest vegetation caused by air pollution (forest death) created enormous pressure on politicians and industry to reduce SO_2 the emissions believed to be responsible for this environmental damage. As large combustion plants in the electricity supply industry were by far the largest source of SO2 emissions, it was obvious that these emissions had to be reduced significantly if the environmental situation was to be alleviated (Wätzold, 2004). This led to the 1983 Ordinance on Large Combustion Plants.

The Ministry of the Interior (BMI), in charge of pollution control at the end of the 1970s, pressed for tighter emission limits. The BMI accepted that through higher electricity prices, private and industrial electricity consumers would have to pay the pollution abatement equipment in the end. Communication with industry facilitated an exchange of views on feasible technological options to reduce SO_2 emissions. The electricity suppliers were concerned about the possibilities to reach the emission limits within the given timeframe, especially installation of de-nitrification and de-sulphurisation systems, because they should be developed by German suppliers. A special problem was the high sulphur content in German coal.

The striking characteristic of the political evolution that led the Ordinance on LCP was that it constituted a continuous development towards stricter rules. Forest death became manifest in many forests and put enormous pressure on politicians to act. The fears of the electricity supply industry that desulphurisation technologies were not advanced enough to ensure an SO_2 emission limit of 400 mg/m³ and that the schedule was too tight to enable the techniques to be first tested in pilot plants, were only partly considered.

The implementation of the Ordinance was accompanied in North Rhine-Westphalia (NRW), the German federal state with the highest number of large combustion plants, by a voluntary agreement which the government of NRW negotiated with the North Rhine-Westphalian electricity supply industry in 1984.

NRW wanted to reduce the emissions even faster and more effectively than provided because it wanted to respond to the high public concern about forest death. As the German state with the highest number of large combustion plants, NRW was determined to set a good example and to demonstrate that the emission limits and deadlines set in the ordinance were realistic and attainable.

The electricity suppliers participated in the EMP in order to show their willingness to actively contribute to solving environmental problems. They also benefited from the EMP insofar as the plan's tight timetable required permitting authorities to carry out the authorisation procedures as swiftly as possible and thus gave electricity suppliers more certainty for their time planning. It was also relatively easy for the electricity suppliers to promise ambitious emission reductions, because their regional monopolies enabled them to transfer the costs to their customers.

The Ordinance led to the reduction of SO_2 emissions by more than 90% compared to 1980 levels in Western Germany. *Figure 9* shows the annual ceilings set in the voluntary agreement. Now the emissions are only about 50% of the ceilings. One reason for the fast reductions 1987-88 was that one big company decreased its SO_2 emissions by about 110,000 tons between 1984 and 1987 by applying a technique which involves the addition of lime before or during the combustion process. This simple technique allows SO_2 emissions to be quickly reduced, but only to a limited extent. It was later followed up with more advanced flue gas de-sulphurisation.

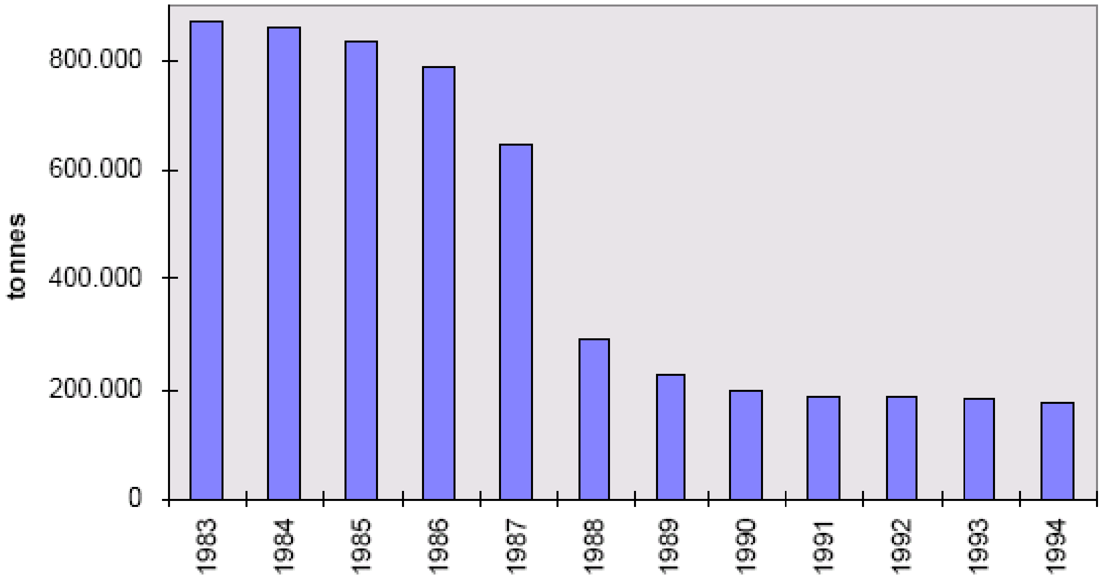


Figure 9 The annual ceilings of EMP in North Rhine-Westphalia in Germany.

A survey of West German electricity suppliers concerning the investments in FGD they had made due to the enactment of the Ordinance concluded that for the whole of West Germany € 7.3 billion was spent. This corresponds to specific investment costs €77/KWth. In the survey, electricity suppliers were also asked to provide data on the running costs of their FGD systems. On the basis of their answers, it was estimated that the specific operating costs amount to €0.01/kWh. The figure includes costs for resource and energy use, personnel, maintenance, capital servicing, and miscellaneous costs. The investments in desulphurisation plants in the North Rhine-Westphalian electricity supply industry amounted to over €4.1 billion.

It was considered whether this could have been done more cheaply by allocation of activities. For example, some LCPs could have reduced their SO_2 emissions less at the expense of other LCPs (for which emission reduction is less costly) that would otherwise have reduced their emissions even further. It was concluded that the cost savings would have been rather because the reallocation possibilities were rather small (Wätzold, 2004). The reason is that cost savings could only take place if FGD systems could be avoided on the large plants and this would not have achieved the emission reductions. Although the Ordinance did not stimulate the development of new abatement technologies, it was very successful in speeding up the diffusion of FGD systems in Germany on a large scale.

In fact, Germany achieved over compliance on SO_2 reductions. The reasons for this are many, but the Ordinance played a clear role together with different other measures in other German States. There was an effective monitoring and enforcement system, which the authorities showed they were willing to apply for severe sanctions in case of non-compliance. The potential for over compliance was also due to the enormous political pressure to stop the visible forest death and the electricity suppliers as a monopoly could send the abatement cost to the consumers (Wätzold, 2002).

2. ASSESSMENT OF THE EFFECTIVENESS

2.1. Environmental effectiveness

This section looks at how the legislation, CLRTAP and other initiatives affected acidification, eutrophication and ground level ozone.

2.1.1. Emissions

Between 1990 and 2000, emissions of acidifying pollutants have decreased in the EEA-31[19] by 40 %. The emission reduction in EEA-31 are primarily due to large reductions of primary emissions of NO_x (– 27 %) and SO_2 (– 60 %), achieved through improved flue gas treatments, fuel switching, use of low sulphur fuels in power stations and the introduction of catalytic converters for cars. Reductions in emissions of acidifying gases in the main emitting sectors (1990–2000) were: energy industries – 48 %, industry (energy and processes) – 51 %, other (energy and non-energy) – 54 %, transport – 25 % and agriculture – 17 %. Emissions of ozone precursors have been reduced in the energy industries sector by – 34 %, industry (energy and processes) – 26 %, other (energy and non-energy) – 21 %, transport – 31 % and agriculture – 28 %.

In 2000, the relative EEA-31 weighted emissions of acidifying pollutants were split between ammonia (29 %), NO_x (32 %) and SO_2 (39 %). The energy industries sector is primarily responsible for the larger proportion of SO_2 emitted in the AC-13. Within the EEA-31, the most significant emission sources for these substances were energy industries, agriculture, transport and industry (summed 93 %).
In 2000, the emissions of NH_3 and NO_x contributed almost equally (48 % and 52 %, respectively) to relative EEA-31 emissions of eutrophying pollutants in 2000. In terms of sector contributions, the most significant emission sources across the EEA-31 countries were the agriculture, transport, and energy industries sectors. A similar sector breakdown was observed for both the EU-15 and accession countries.

The emissions trends in EU-15 for different sectors are shown in *Figure 10.*

---

[19] The 31 European countries, members of the European Environmental Agency

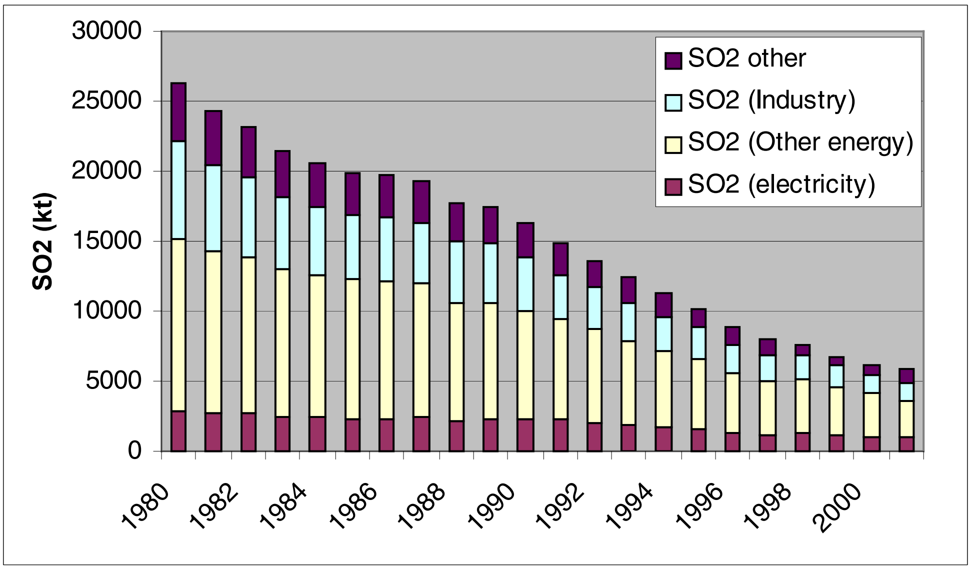


Figure 10 SO_2 emissions in EU-15 from main sectors, EEA, 2004.

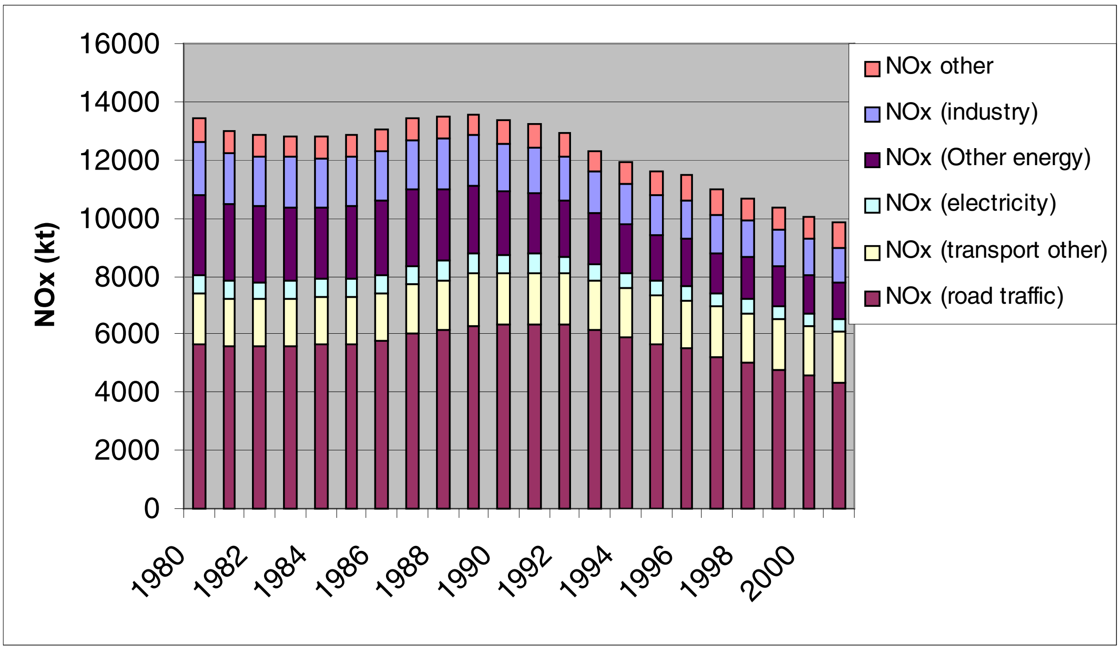


Figure 11 NO_x emissions in EU-15 from main sectors, EEA, 2004.

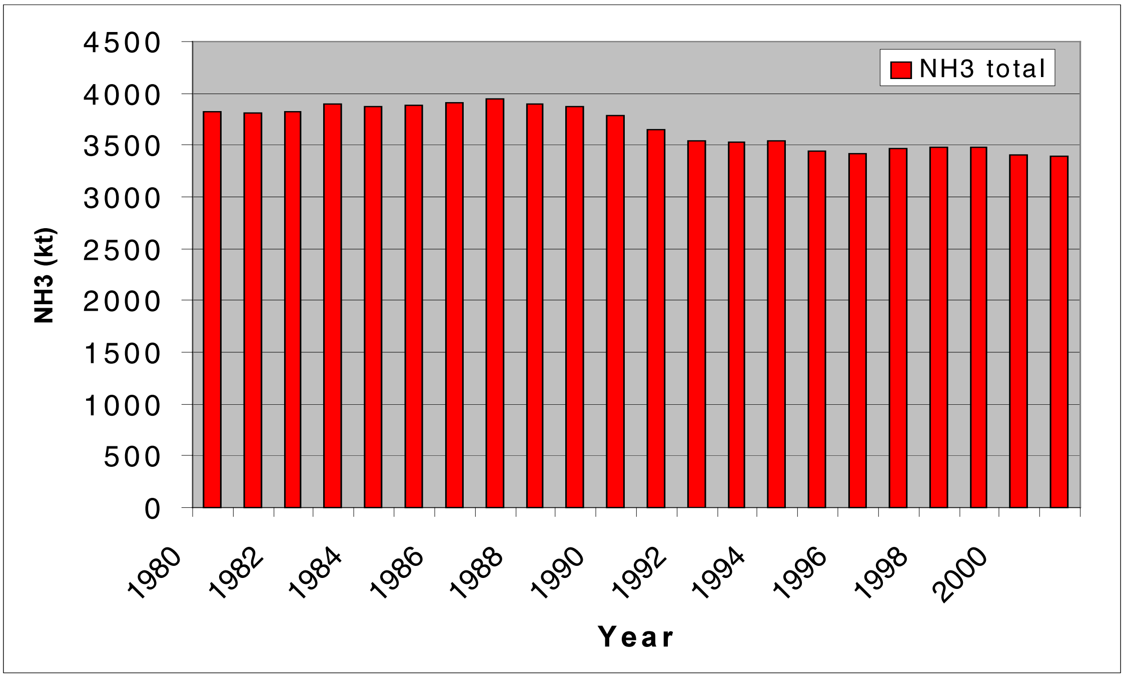


Figure 12 NH_3 emissions in EU-15, EEA, 2004. The completely dominating source is agriculture.

The trends of the emissions have been assessed by scenario calculations (Amann et al. 1999). The 1990 situation has been compared with different scenarios in connection with the evaluation of the NEC Directive. In *Table 8* the situation in 1990 has been compared with the reference scenario (CLE), which is more or less is based on the present legislation. The reductions have generally been estimated to become very high for SO_2, NO_x and VOCs in the EU-15 countries, except Greece, Spain and Portugal. The reductions were estimated to be significantly lower in the non-EU countries, except in Switzerland, Norway, Czech Republic, Slovenia and a few others, but there are large differences for the different pollutants. In these data there are no indication that countries like Norway and Switzerland obtained larger reductions due to more strict legislation, but it should be noted that their emission levels in 1990 already was rather low.

Note that the emissions of NH_3 do not decrease significantly.

Table 8 The emissions in Europe estimated for a reference scenario corresponding to the existing legislation compared with the situation in 1990, (Amann et al. 1999)

	NO_x			VOC			SO_2			NH_3			Total
	1990	CLE	Red. (%)	1990	CLE	Red. (%)	1990	CLE	Red. (%)	1990	CLE	Red. (%)	Cost (M€/year)
Austria	192	103	46	352	205	42	93	41	56	77	67	13	1093
Belgium	351	191	46	398	193	52	336	193	43	97	96	1	1704
Denmark	274	128	53	162	85	48	185	94	49	77	72	6	623
Finland	276	152	45	213	110	48	232	155	33	40	31	23	889
France	1867	858	54	2399	1223	49	1250	448	64	805	777	3	8659
Germany	2662	1184	56	3066	1186	61	5280	581	89	757	572	24	13813
Greece	345	422	-22	336	267	21	504	546	-8	80	74	8	1482
Ireland	113	70	38	111	55	50	178	66	63	127	130	-2	618
Italy	2037	1130	45	2053	1159	44	1679	567	66	462	432	6	9644
Luxembourg	22	10	55	19	7	63	14	8	43	7	9	-29	98
Netherlands	542	280	48	490	233	52	201	73	64	233	141	39	2588
Portugal	208	177	15	217	163	25	284	141	50	71	67	6	1530
Spain	1162	847	27	1048	695	34	2189	774	65	352	383	-9	6495
Sweden	338	190	44	492	291	41	119	67	44	61	61	0	1554
UK	2839	1315	54	2663	1628	39	3805	1086	71	329	297	10	7964
EU-15	13226	7056	47	14017	7502	46	16348	4839	70	3576	3208	10	58754
Albania	24	36	-50	30	41	-37	72	55	24	32	35	-9	0
Belarus	402	316	21	279	309	-11	843	494	41	219	163	26	0
Bosnia-H.	80	60	25	46	48	-4	487	415	15	31	23	26	1
Bulgaria	354	297	16	198	190	4	1841	846	54	141	126	11	157
Croatia	83	91	-10	79	111	-41	180	70	61	40	37	8	52
Czech Rep.	522	296	43	322	367	-14	1873	366	80	107	108	-1	979
Estonia	84	73	13	44	49	-11	275	175	36	29	29	0	0
Hungary	214	198	7	206	174	16	913	546	40	120	137	-14	586
Latvia	117	118	-1	51	56	-10	121	104	14	43	35	19	0
Lithuania	152	138	9	104	105	-1	213	107	50	80	81	-1	0
Norway	220	178	19	308	301	2	50	32	36	23	21	9	623
Poland	1209	879	27	709	807	-14	2999	1525	49	505	541	-7	3342
Moldova	87	66	24	53	42	21	197	117	41	47	48	-2	0
Romania	518	458	12	483	504	-4	1331	594	55	292	304	-4	157
Russia	3485	2628	25	3332	2787	16	5012	2208	56	1282	894	30	715
Slovakia	207	132	36	143	140	2	548	137	75	60	47	22	423
Slovenia	60	36	40	60	40	33	200	76	62	23	21	9	128
Switzerland	163	79	52	291	144	51	43	26	40	72	66	8	949
Macedonia	39	29	26	20	19	5	107	81	24	17	16	6	1
Ukraine	1888	1433	24	1074	851	21	3706	1488	60	729	649	11	328
Yugoslavia	211	152	28	124	139	-12	585	269	54	90	82	9	92
Non-EU	10118	7692	24	7956	7224	9	21595	9729	55	3980	3462	13	8534

2.1.2. Environmental Impact

In 2000 acidifying deposition was above critical loads in parts of central and Northwest Europe. Eutrophying deposition above critical loads was more widespread.

Nonetheless, sulphur deposition had fallen significantly by the year 2000, and large areas are now protected from further acidification. Calculations indicate that by 1999 most countries had made notable progress towards the 2010 targets to reduce areas still subject to increasing acidification.

Reductions in nitrogen deposition have been more limited and scattered, reflecting the lack of a systematic reduction in the supply of potentially eutrophying pollution. For example the observed nitrogen input to north European coastal waters has not decreased since the early 1990s. A few countries have experienced notable decreases in the land area subject to further eutrophication between 1990 and 1999, but several countries are believed to have worsening problems.

Sulphur in precipitation and air has been measured over a sufficient area and time period to allow the actual changes in sulphur deposition to be described. Observed wet depositions can be added to calculated direct ‘dry’ deposition of gases and particles to the surface based on observed sulphur air concentrations to give the total sulphur deposition at any time. *Figure 13* display the differences in the so obtained total deposition (wet and dry) of potentially acidifying sulphur between 1990 and 2000 are displayed. Values for 1990 have been estimated as the average of observations for 1990–92, and those for 2000 as the average of observations from 1998–2000. These three-year average values reduce the potentially misleading effect of interannual variability.

For large stretches of northern, western and central Europe sulphur deposition in 2000 has fallen by 50% or more, as compared to the start of the decade.

The total rate of nitrogen deposition (*Figure 14*) is here divided between the ‘oxidised’ component, which arises from industrial and transport emission sources, and the ‘reduced’ component arising principally from agriculture. The unchanging level of deposition in precipitation experienced at these stations during the 1990s for both forms of nitrogen is striking. Air concentrations have not been used to derive estimated trends of dry deposition of nitrogen. The observed lack of changes in nitrogen deposition during the 1990s does not reflect the reduction in emissions of NO_x in Europe. The reason for this is not understood.

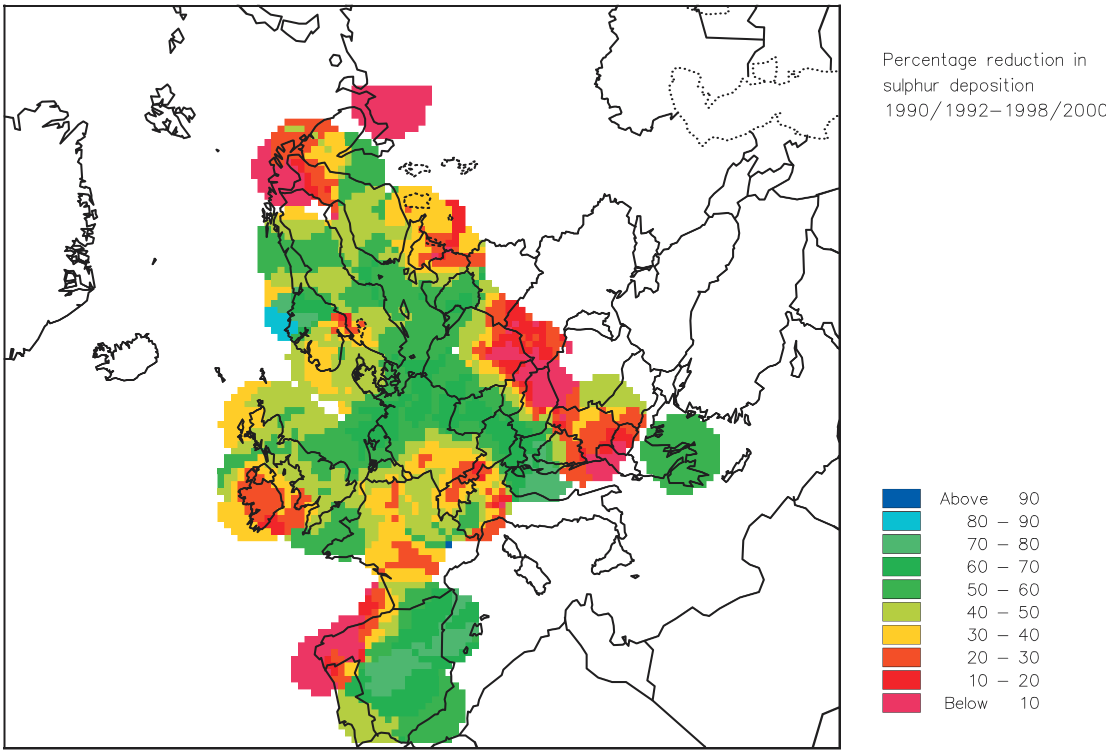


Figure 13 Percentage reduction in observed annual sulphur deposition from 1990/92 to 1998/20001). (EEA, 2003c).

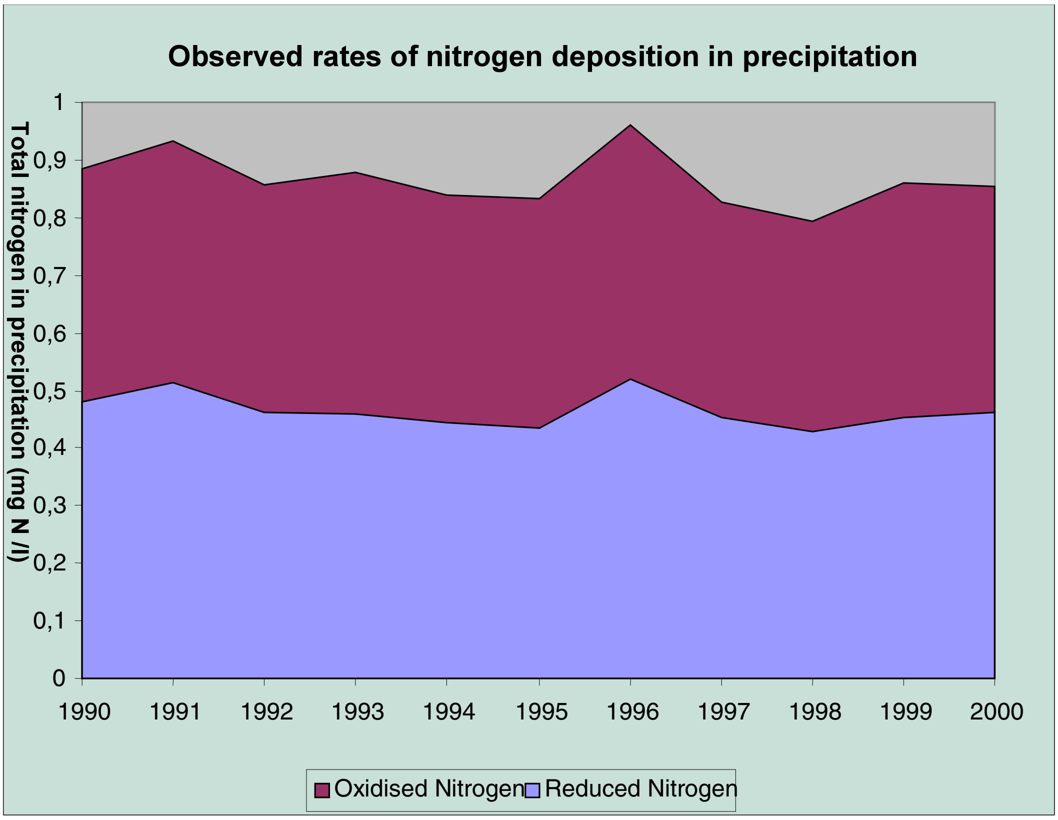


Figure 14 Observed rates of nitrogen deposition in precipitation. Precipitation weighted average annual deposition rates across 36 stations in 15 countries. (EEA,2003c).

To understand the combined impact of these differing changes in acidifying sulphur and nitrogen deposition, it is necessary to combine the components and to compare this with estimated ecosystem tolerance to acidifying pollution. Calculated estimates of the transport and deposition of acidifying compounds have been obtained from EMEP, with the disclaimer that current calculation routines are under further development and should be taken as only indicative of the actual situation.

These estimates are combined with ecosystem data to indicate the degree of protection from further acidification which ecosystems are currently believed to experience. The concentration of impact (deposition above critical load) around Northwest Europe is pronounced. Indeed, this impact concentration is perhaps greater than shown, as many areas shown as having > 80 % protection are actually 100 % protected.

It is also to be observed that the areas which have seen greatest improvements with respect to sulphur supply are nevertheless still adversely affected, likely in part at least due to nitrogen deposition.

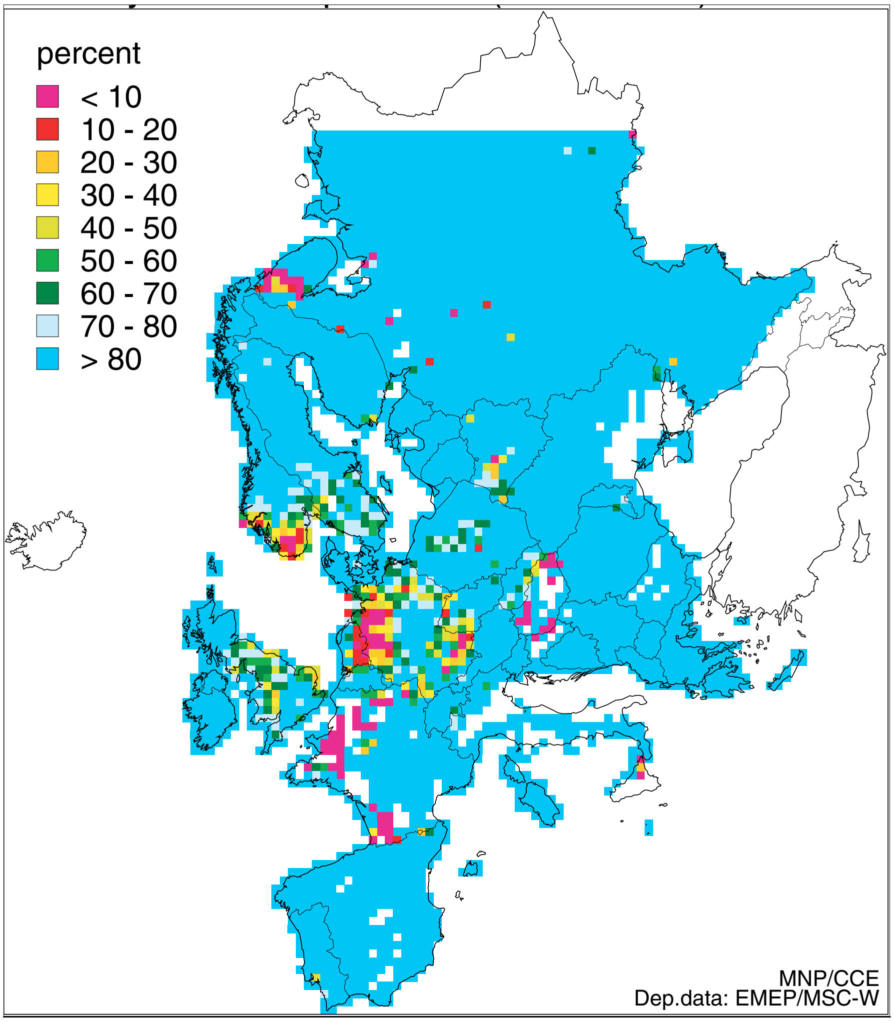


Figure 15 Percentage of ecosystems protected from acidification, 2000. (EEA, 2003c).

Eutrophication of waters and soils can arise as a consequence of nitrogen supply. *Figure 16* displays the monitored changes in this supply at the European scale, revealing little change during the last decade. There are regional differences, and the observation networks around north European marine regions allow the difference in potentially eutrophying nitrogen supply to be seen. For the North and Baltic Seas a decline was observe in nitrogen supply during the first years of the decade, but thereafter little change was seen. For the North Sea there has been no observable decrease in nitrogen supply.

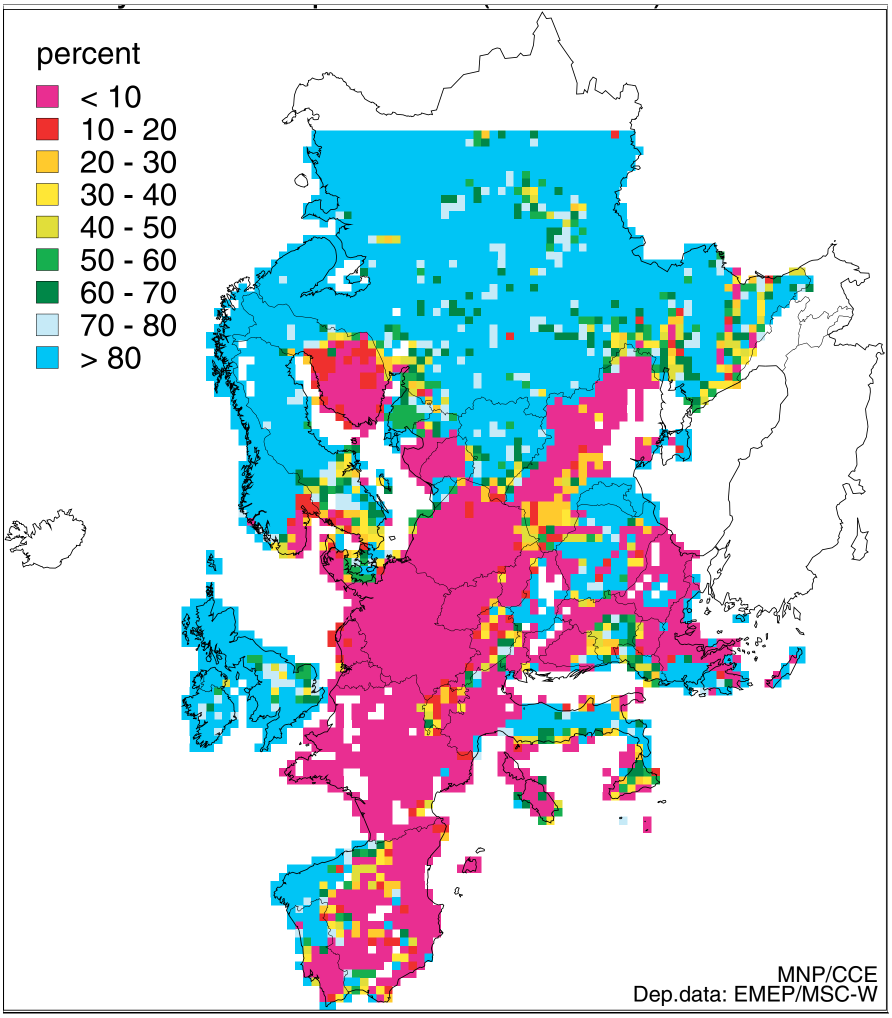


Figure 16 Percentage of ecosystems protected from impact of eutrophication through atmospheric deposition of nitrogen. (EEA, 2003c).

2.2. Costs

2.2.1. Cost-effectiveness

Evaluation of the cost-effectiveness of measures against acidification in the Netherlands shows that the average cost for reduction of the NO_x and SO_2 emissions are about 3 Euro per kg and 1 Euro per kg SO2. Energy savings, the implementation of national limits on heating installations and the placement of Selective Catalytic Reduction installations (SCR) in industry were relatively cheap measures: 0-2 Euro per kg NO_x. The costs for SCR seem not to have been more than 1.5 Euro per kg. NO_x, whereas the catalytic converter in road transport was relatively expensive at about 5 Euro per kg NO_x. It has to be taken into account that NO_x reductions in this sector also lead to reduced emissions of VOC, carbon monoxide and particulate matter. The pollution by traffic takes place in residential areas as opposed to industrial activities, for example, so that local air quality is strongly influenced by traffic. According to an indicative estimate, 1 kg NO_x reduction in traffic emissions in 2010 is more effective - 3 to 17 times - in reducing NO_2 concentrations in hotspots than the same reduction in other target sectors.

In an exploratory study on the effects and costs of a number of policy options to reduce NO_x and SO2, the average cost effectiveness was estimated at about 4 Euro per kg for both NO_x and SO_2 (Smeets et al., 2002). On the basis of these figures it was conclude that the marginal costs of emission reductions are increasing, both for NO_x and SO_2. For shipping (domestic and deep-sea) a few relatively cheap measures are still possible. However, they can only be realised at the international level. For the

Netherlands measures for shipping do not contribute to realising EU emission ceilings, but do contribute to the reduction of deposition and concentrations. Compared to other European countries, the costs of extra measures in the Netherlands per kg of emission reduction are high related to unit GDP, because still cheaper measures are available abroad.

A report produced for the Swedish Ministry of the Environment, found that cost estimates for implementing the UNECE Protocols on acidification and the 1988 Large Combustion Plant Directive in the UK forecast increases in electricity generating costs of up to 30%, based on the assumption that plant would need to be fitted with flue gas desulphurisation equipment. In reality, costs increased by only 2.5% to 5% over a 15 year period. The study also found that the costs of the catalytic converter technology to meet the Euro 1 standards, including adoption of catalytic converters on cars, were significantly overestimated before introduction (SEI, 1999).

2.2.2. Costs and Benefits

Estimation of economic impact and the costs and benefits of controlling e.g. acid rain, has been an issue both in Europe and in the USA since the 1970s. However, uncertainties in relationship between deposition and effects were so large that the role of cost-benefit analysis has been limited. In Europe, the emphasis has instead been on critical loads. The RAINS model has played an important role in deciding where emission reductions would have the largest effect in reducing the gap between the present deposition and the critical loads.

Recently there has been greater interest in cost-benefit analysis for environmental policy making in Europe. Although the benefit estimates are uncertain and limited in scope, the most recent cost-benefit analyses point clearly to reduced harmful health effects as the major benefit in monetary terms from further controlling acid precursors. *Table 3*, presents some of the benefits of meeting the emissions reduction targets of the 1999 Gothenburg protocol have (Holland et al, 1999).

Table 9 Quantified damages across Europe from the Gothenburg Protocol pollutants in 1990 and incremental benefits in moving to the Protocol ceilings scenario (values in million Euro, base year 1990). (Menz & Seip, 2004).

	Damages for Protocol pollutants in 1990	Reduction in damages by moving to the protocol ceiling scenarios
Health – Morbidity	47 000	18 000
Health – Mortality[20]	230 000	95 000
Materials	1 800	1 200
Crops	27 000	7 800
Timber production[21]	2 200	770
Ecological damage	Not monetized	
Visibility	Not quantified	5 600

The total cost of reaching the emission ceilings under the Gothenburg Protocol is expected to be around 70 billion Euros per year for Europe as a whole. This includes the cost of other European initiatives, which will contribute to meet the emission ceilings, e.g. the EU directives on emissions from cars and trucks.

The benefit of meeting the protocol's emission ceilings have been estimated to roughly 200 billion Euros per year. These benefits results mainly from significant reductions in negative effects of ozone and particulate matter on human health. Other effects include agricultural productivity and reduced

---

[20] The values were estimated using values of life years lost (VOLY). By using values of statistical lives, the results are considerably higher; the damage reduction becomes 160 000.

[21] Only effects of ozone have been quantified.

damages on buildings and materials. The benefit of reduced damage on ecosystems due to acidification and eutrophication and on cultural objects and historical buildings and statues are not included, because of difficulties in ascribing a monetary value (UNECE, 1999).

Figure 17 Estimates of different contributions to reduced NOx and SO2 from different sectors have been estimated in the Netherlands.

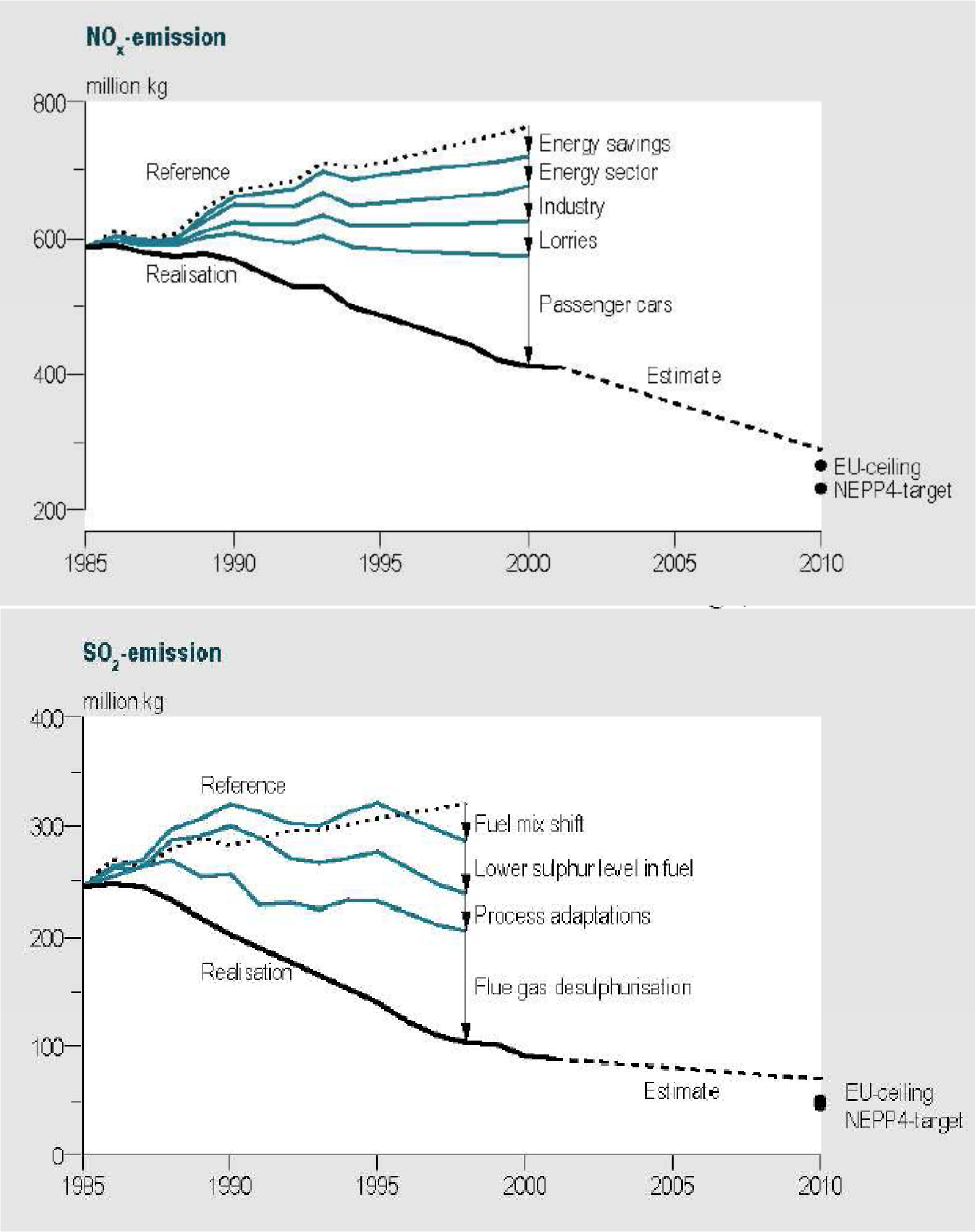


Figure 10 Different contributions to reduced NO_x and SO_2 from different sectors.

2.2.3. *Co-production of electricity and heat*

In conventional thermal power plants, typically 45 % to 70 % of the energy content of the fuel disappears as waste heat. Combined Heat and Power (CHP) combines electricity generation with heat recovery, resulting in increased energy efficiency and hence less environmental impact per unit of electricity produced. Additional benefits can be realised if the CHP scheme uses low emissions fuels, including natural gas or renewables as opposed to coal or oil. From 1994 to 1998, EU generation from CHP increased from 9% of gross electricity generation to 11%, 7% short of the EU indicative target of 18% by 2010. Penetration of CHP in Denmark and the Netherlands is particularly high (more than 50%) as a result of government support. Liberalisation of energy markets in Finland and the United Kingdom has also stimulated investment in CHP. However, lower electricity prices may act against more investment in CHP plants, which are capital intensive. This has already been the case in Germany where CHP generation has decreased (EEA, 2001).

2.3. Compliance and enforcement

The EU legislation and the conventions together have generally been a success, and have been implemented in most of the European countries. The emission targets were achieved in most of the EU countries except Portugal, Greece, Spain and Ireland during 1990-2000, and there is a good chance that the goals for 2010 will be reached. This is also the case in most of the Accession countries. Significant emission reductions occurred despite the growth in population, economic output and energy input into the economies of Europe. Abatement measures prompted by EU legislation and the CLRTAP agreements must therefore have had a substantial impact.

All Member States are obliged to transpose the directives into national legislation. However, the Member States were free to implement the directives in different ways, leading in practise to different stringency on e.g. the emission limits. The following examples from Spain and Germany illustrate the different approaches on implementation of the EU legislation (Börzel, 2003).

Compliance with the European air pollution control policies in Spain is improving, but the BATNEEC requirements are not systematically enforced either on existing combustion plants or on monitoring networks. It might finally merge within implementation of the IPPC Directive. The IPPC Directive stipulates that permits for industrial plants must set emission limit values based on what is achievable by BAT, but under economically and technically viable conditions. Technical working groups prepare BAT reference documents (BREFs), which the Member States have to incorporate in the environmental permitting procedures. Spain participates in many of these groups under the European IPPC Bureau in Seville. Whether those standards will be ultimately enforced, remain to be seen.

Since the two European Air Pollution Directives were modelled after the German legislation, Germany has not had any compliance problem (see above), nor difficulties in meeting the reduction targets set by the LCP Directive. In fact, it was several years ahead of the European timetable.

While the two European Directives on air pollution fit the German policies, they exerted considerable pressure for adaptation on Spanish air pollution policies. The required modernisation of Spanish industrial plants imposes high costs, which neither the industry nor the public authorities wanted to bear. As a result the Industrial Plant Directive was not been implemented at all in practise. The LCP Directive was simply absorbed into the Spanish system leaving substantial parts non-applied. The Spanish administration showed little willingness to deal with the necessary costs. Only when the social actors and municipalities formed a powerful coalition pressing both the central administration and the industry, Spanish industry and public authorities started to become active. Since then, Spain has reduced the SO_2 emissions considerably.

With respect to environmental goal attainment, one study found a significant over compliance with the national SO2 emission reduction targets set out in the LCP-Directive (Eames, 2000). In each case, the environmental outcomes obtained were the product of quite distinct national policy processes. Indeed, the LCP-Directive itself was found to have had no impact in three of the four cases (Germany, the Netherlands and France), and only limited impact in the fourth, the UK. The principal factors explaining over compliance where found to include:

- Public and political awareness
- Interactions between the market structure and type of policy instrument
- Interactions with national energy policy
- The use of compliance plus negotiated agreements
- The cost structure of flue gas de-sulphurisation
- Technological learning effects, and
- Anticipation of further regulation

Only in Germany were classical monitoring and enforcement activities identified as a significant factor affecting the environmental outcome obtained. The picture with respect to administrative compliance has been far more mixed. However, the incidents of administrative non-compliance documented were in the main fairly trivial.

With respect to cost-effectiveness, significant variations in the manner in which the respective national policy outcomes were obtained were also observed, and was principally determined by the choice of policy instrument. A number of significant interactions between the type of policy instrument and market structure, and both the environmental outcome and cost effectiveness of the implementation process were identified. This demonstrates that implementation is far more complex than simply transposition, monitoring and enforcement and requires attention to industrial structure and policy interaction (Eames, 2000).

2.4. Administrative feasibility

The CLRTAP was not very efficiently transposed to national legislation, which resulted in delayed ratification in many countries (see paragraph 1.3.1). There were no real penalties except political pressure for not being in compliance with the agreements. The EU legislation was more instrumental in getting national measures for compliance in place in the Member States.

An analysis of implementation of the “old” LCP-Directive in France, Germany, the Netherlands and the UK concludes that the European regulatory framework for abating sulphur emissions, which evolved over the last two decades has been characterised by significant uncertainty, increasing complexity and overlapping requirements (Eames, 2000). Each of the case study countries considered has international obligations both as a member of the European Union and as a signatory to CLRTAP. Each also possesses its own distinctive body of national regulation, developed in accordance with its own legal and administrative traditions. A wide variety of different types of regulatory instrument have been deployed at various times, across varying geographical spaces. These include national and sectoral emissions ceilings and reduction targets, plant-based emission limit standards, technology-based standards, voluntary or negotiated agreements, and controls on the sulphur content of various types of fuel. Regulatory objectives have generally been strengthened over time as scientific knowledge of the environmental damage caused by SO2 increased. In addition the practical scope for abatement have improved (as a result of the retirement of older ‘dirtier’ plant, together with the development and commercialisation of new control technologies and abatement options). As a result implementation of the LCP-Directive could not be examined in isolation. Rather the LCP-Directive is just one piece of a complex, dynamic patchwork of parallel and overlapping policy processes, arising at different governance levels (local, national, European, international).

2.5. Political acceptability

The European countries have in some cases implemented different measures to promote the reduction of the pollutants included in the European legislation. In addition, political pressures played a big role in some countries.

The Nordic countries used economic incentives to promote the reduction measures, especially in relation to energy and process industries, e.g. tax on SO_2 and NO_x, but also local requirements on low sulphur content in fuel and emission standards for new vehicles.
A clear over compliance was obtained on SO_2 reductions in Germany. While the reasons for this are many, the 1983 “Ordinance on Large Combustion Plants”, played a clear role together with an effective monitoring and enforcement system, in which the authorities were willing to apply severe sanctions in case of non-compliance.

3. “GROUND LEVEL OZONE”

3.1. Introduction

The directives and the conventions in relation to ozone were implemented in the national legislation in similar ways as the legislation for acidification and eutrophication.

The ozone problem was of great concern especially in the Mediterranean countries, e.g. Spain, Italy (Milan) and in the central European countries e.g. Germany. Special measures were taken into use, e.g. bans of road traffic in case of summer smog alarms. However, ground level Ozone was soon recognised as a regional problem, which could not be solved isolated in an urban area. Moreover, in connection with the new Ozone Directive, it was realised that it was not possible to comply with limit values recommended by WHO. Therefore interim target values were defined.

The ozone problem in the Northern European countries is mainly a long range transport problem. It is a combination of the relatively high background level in the Northern Hemisphere and episodes with transport of ozone and ozone precursors from Central Europe.

Sweden has set lower limit values for ozone (Air Quality Goals), which leads to smog alarms earlier than the EU standards.

3.2. Emissions Sources

A number of man-made pollutants, such as nitrogen oxides (NO_x) and volatile organic compounds (VOC) cause photochemical activity in atmosphere. Nitrogen oxides are emitted mainly from combustion processes from both mobile sources (e.g. road traffic) and stationary sources (e.g. power plants). VOC are emitted from combustion and also by evaporation of fuels and solvents. Furthermore natural emissions, in particular of hydrocarbon from vegetation, will also contribute to the photochemical activity.

The total emissions of acidifying, eutrophying and ozone formation precursor pollutants from the main sectors in the EEA countries and accession countries are shown in *Figure 8*.

4. LEGISLATION AND MEASURES IMPLEMENTED

The European legislation and other types of agreements affecting ground-level ozone are mainly the Convention on Long-range Transboundary Air Pollution (CLRTAP), the EU directives and different national laws. Must of the relevant instruments have already been described in section 2.2 above. This section focuses on those acts which have not yet been mentioned and which are particularly relevant to the problem of ground-level Ozone.

4.1.1. The VOC Protocol under CLRTAP

This Protocol on volatile organic compounds came into force in 1997. It aims principally at reducing the scale and the number of episodes where the ozone concentrations are particularly high. Most of the signatories have committed themselves to reduce their emissions by at least 30 per cent by 1999, compared to 1988. Some countries have however elected to take an alternative base year. Norway and Canada are confining their 30-per-cent reduction to certain specified areas – so-called Tropospheric Ozone Management Areas (TOMAs), and some small emitter countries were given the possibility of signing the protocol even if they undertook only to freeze emissions. According to officially reported emission data for 2003, 7 of the 21 countries that had ratified the protocol were in remiss. Among these are Finland, Italy, Luxembourg, Norway, and Spain. Between 1988 and 1999 the European emissions of VOC_s decreased by nearly 30 per cent.

4.1.2. The Gothenburg protocol

For details of the Gothenburg protocol see 1.3.6. It aims at significant reduction of acidification, eutrophication, and the formation of ground-level ozone by setting national ceilings for emissions of the four pollutants that give rise to these effects, namely SO2, NO_x, VOC_s, and ammonia. Starting from the critical loads approach, and by attacking several environmental problems and several pollutants simultaneously in a co-ordinated manner, it aims to improve the overall level of cost-effectiveness even further. The European emissions of SO_2, NO_x, VOC_s, and NH_3 is expected to fall by respectively 63, 40, 40, and 17 per cent between 1990 and 2010.

4.1.3. The EU legislation

Up to the early nineties, the EU policy in relation to ground level ozone has focussed on directives setting air-quality standards for a few selected air pollutants. The pollutants were first of all sulphur dioxide and nitrogen oxides, or others to control emissions from certain defined sources such as large power plants and road vehicles, (see paragraph 1.3.7). The acidification strategy was later followed up by requirements on reduction of concentrations of ground-level ozone.
EU directives specifically related to ground-level Ozone, including precursor pollutants, are:
Ozone in ambient air (2002/3/EC)

The objectives of the third Daughter Directive are:

- to establish long-term objectives, target values, an alert threshold and an information threshold for concentrations of ozone in ambient air in the Community, designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole;

- to ensure that common methods and criteria are used to assess concentrations of ozone and, as appropriate, ozone precursors (oxides of nitrogen and volatile organic compounds) in ambient air in the Member States;

- to ensure that adequate information is obtained on ambient levels of ozone and that it is made available to the public;

- to ensure that, with respect to ozone, ambient air quality is maintained where it is good, and improved in other cases.

The directive replaces Council Directive 92/72/EEC on air pollution by ozone.

Emissions of VOCs from storage and distribution of petrol (94/63/EC)
It covers the chain of distribution from terminal to service station, but not the evaporative emissions that take place when cars are refuelling.

Use of solvents in industry (99/13/EC)

The aim is to reduce the emissions of volatile organic compounds arising from the use of organic solvents in some twenty industrial processes. Note: In 2004, the Commission proposed a complementing Directive covering the VOC content of products such as decorative paints and varnishes. Studies made by the Commission have shown however that the emissions from such products, as well as from operations such as vehicle refinishing, could be cost-effectively reduced. The Commission has indicated its intention to come forward with a proposal for a directive, probably by the summer of 2002.

Emissions from engines for non-road machinery (97/68/EC)
The directive applies especially to diesel engines with power outputs of 18 to 560 kilowatts. In December 2000 the Commission presented a proposal to widen the scope of this directive so as to cover small spark-ignition (petrol) engines such as are used in lawn movers, chain saws, etc. Since most of these smaller engines are of the two-stroke type, the biggest reduction in emissions will be for VOCs. Emissions from tractors used for instance in agriculture and forestry are regulated by directive 2000/25/EC.

5. ASSESSMENT OF THE EFFECTIVENESS

5.1. Environmental Effectiveness

The section below analyses how the legislation, CLRTAP and other initiatives affected ground level ozone in the Member States.

5.1.1. Emissions

Between 1990 and 2000, emissions of ozone formation precursor gases have decreased in the EEA-31 by 29 %. All emission reductions have been realised despite a general increase in economic production, energy consumption, and population across the EEA-31 region.
The decreases are primarily due to large reductions of primary emissions of NO_x (– 27 %) and NMVOCs (– 29 %), achieved through improved flue gas treatments, fuel switching, and the introduction of catalytic converters for cars. Emissions of ozone precursors have been reduced in the energy industries sector by – 34 %, industry (energy and processes) – 26 %, other (energy and non-energy) – 21 %, transport – 31 % and agriculture – 28 %.

The general trends of the anthropogenic ozone precursors are shown in *Figure 11* (section 2.1.1) and *Figure 18*. It is clear that the emission reductions became larger after introduction of three way catalysts, starting around 1990.

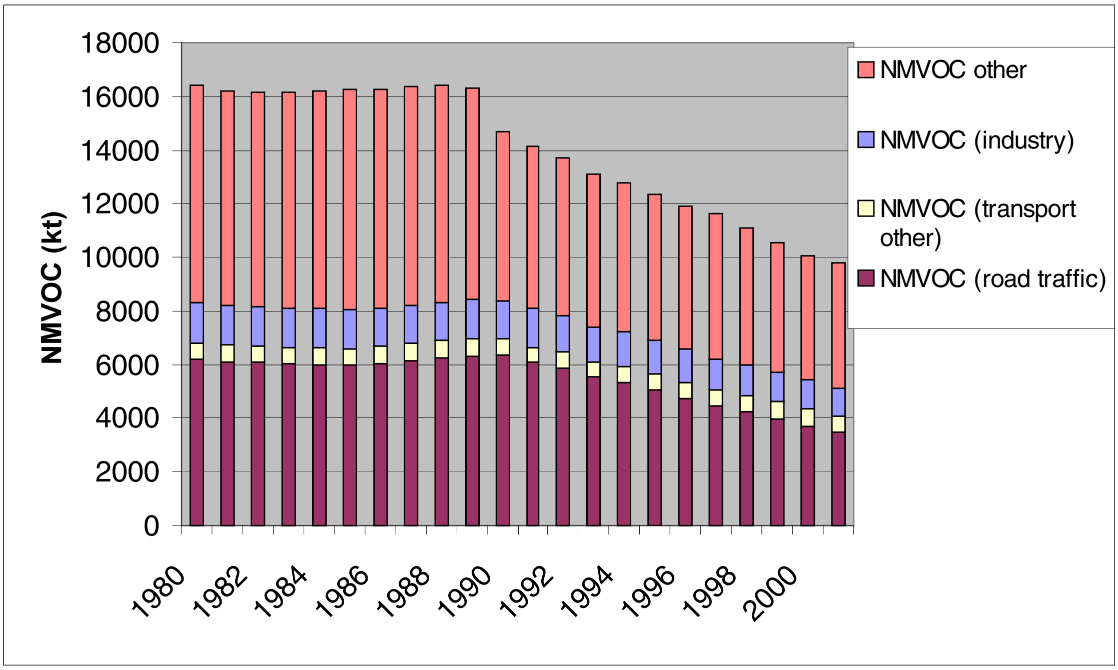


Figure 18 NMVOC emissions in EU-15 from main sectors (EEA, 2004).

Of the four pollutants (CH_4, CO, NMVOC and NO_x) that contribute to the formation of ground-level ozone, emissions of NMVOC (comprising 39 % of the total weighted formation potential in EEA-31) and NOx (46 %) were the most significant in 2000. Within the EU-15, contributions by NMVOC and NOx to total weighted emissions were similar to the EEA-31. For the accession and EFTA-4 countries, NMVOC contributed 34 % and 49 % respectively of the total ozone precursor emissions, and NOx contributed 48 % and 40 % in the respective country groupings. For all regions, carbon monoxide and methane contributed around 15 % and 1 % respectively. Road transport is the dominant source of ozone precursors for the EEA-31 (37 %). Other significant sources included solvents use, industry and energy industries (summed 37 %).

For emissions of ozone precursors, only four EU Member States (United Kingdom, Germany, Netherlands and Finland) are below the linear target path towards meeting their obligations of emissions reductions under the EU National Emission Ceilings Directive (NEC). Emissions of five countries, Portugal, Spain, Greece, Ireland and Belgium are substantially above the linear target path, and will require substantial future emission reductions to meet their respective emission targets. Of the accession countries, eight are below the linear target path to the 2010 targets, and only Slovenia is above the linear target path. In order to meet the future targets, Slovenia but also Hungary, Poland and Czech Republic will require significant emission reductions.

The EU is more than half way towards meeting the 2010 targets of the NEC Directive for acidifying pollutants, although several Member States (Greece, Portugal, Ireland and Spain) are less than half way to their 2010 targets and above the linear target path towards their respective targets. Of the accession countries, all are below the linear path to the Gothenburg protocol target, and four countries (Latvia, Lithuania, Czech Republic, Slovakia) substantially so. A number of accession countries have already reached their respective emission targets.

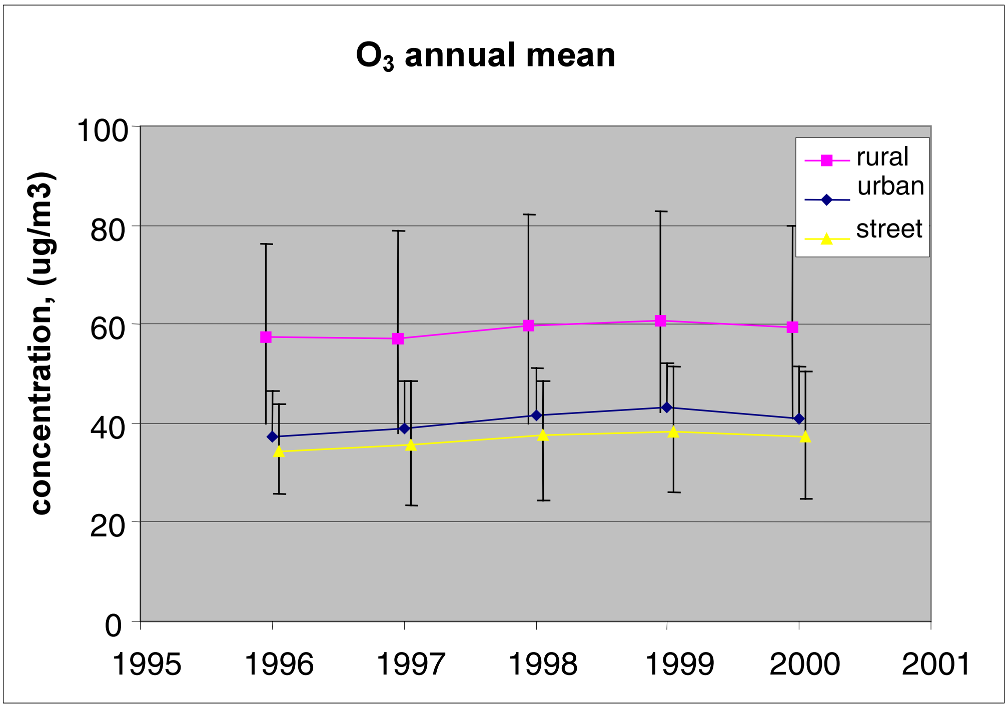
5.1.2. Environmental Impact

The air quality limit and target values for ozone that are to be met by 2005–2010 are currently exceeded extensively in European cities, and in rural areas as well.

The tendency in concentrations is complex: Annual averages have been increasing (about 8 % since 1996, averaged over all station types), while maximum and high percentiles of hourly concentrations have been decreasing over the decade. The health-related ozone indicator of the EU Directive (26th highest daily maximum 8-hour average concentration) has been rather unchanged since 1996, when averaged over a large, consistent set of stations.

Ozone data are available in AirBase from a substantial number of stations in many countries since 1996, the number increasing each year. In 2000, the ozone data reported to AirBase included in total 1207 monitoring stations in 29 countries with data satisfying the completeness criteria of the Air Quality Directives, of which 335 are in rural areas, and the rest distributed in about 650 cities. The total population in those cities was 93 million. Most of the stations are located in EU-15, with only about 80 stations in the accession countries.

Figure 19 shows the change in ozone concentrations in Europe since from 1996 and onwards. The graphs show that there is a tendency towards increasing ozone when looking at the annual average concentrations, while the more short-term concentration levels (represented by the 26th highest daily 8-hour average, corresponding to the target value of the Ozone Directive) show an almost unchanged averaged level since 1996, in all three area types (rural, urban, traffic hot-spot). The short-term concentrations at the most exposed rural stations were highest in 1998 and in 2000, indicating that ozone episodes were most severe then.



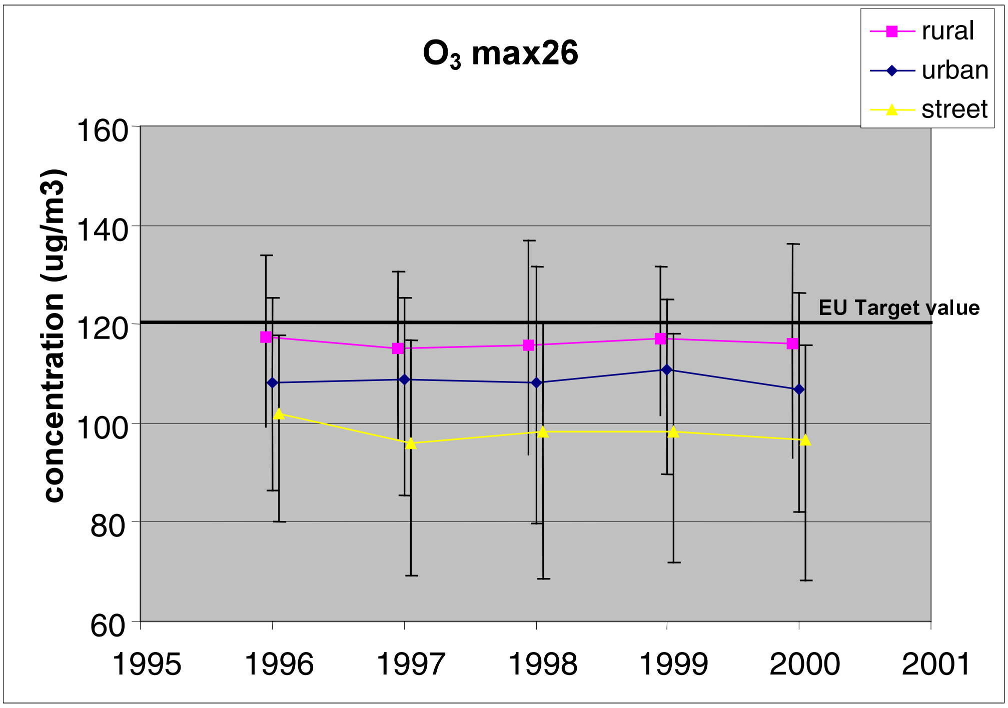


Figure 19 Ozone, interannual variations, 1996–2000. Indicators: Annual mean and the 26th highest daily 8-hour average per year (the EU Target Value indicator). All stations with 4 or 5 monitoring years. Vertical bars: 10th and 90th percentiles. (EEA, 2003c).

Maximum concentrations recorded in 2000 were close to 50 % above the target value. On the average, the concentrations at stations with exceedence of the target value were 11 %, 7 % and 9 % above the target value respectively for rural, urban and traffic stations.

In conclusion, exceedences of the ozone target value are found to be widespread in Europe, and the relevant concentration parameters have not been reduced since 1996.
Between 1996 and 2001, 20-30% of the urban population was exposed to ozone concentrations above the EU target value. The exposure of urban populations to pollutant concentrations above limit and target values is strongly influenced by climatic conditions and is not evenly distributed throughout Europe, see (*Figure 20*)

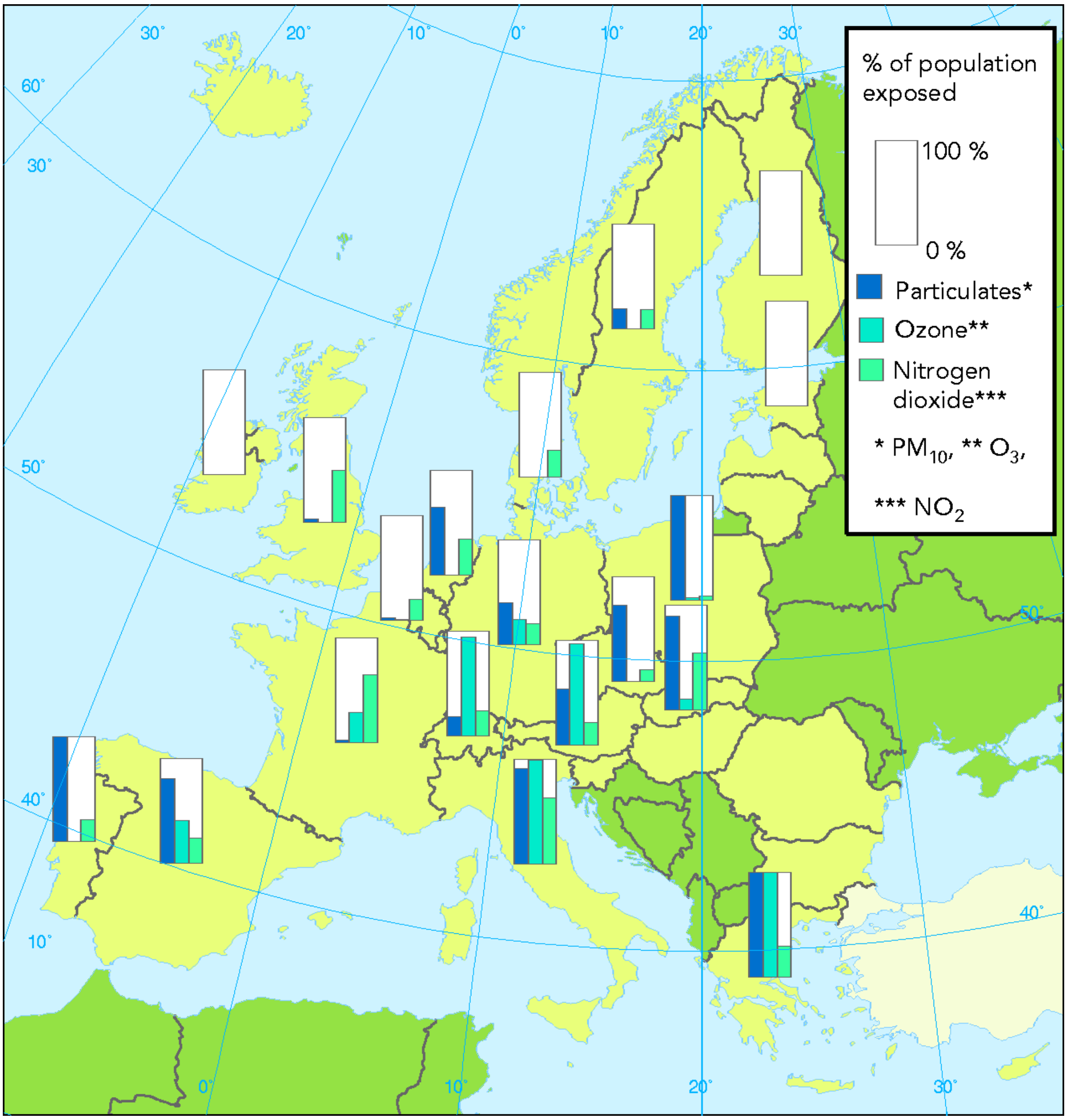


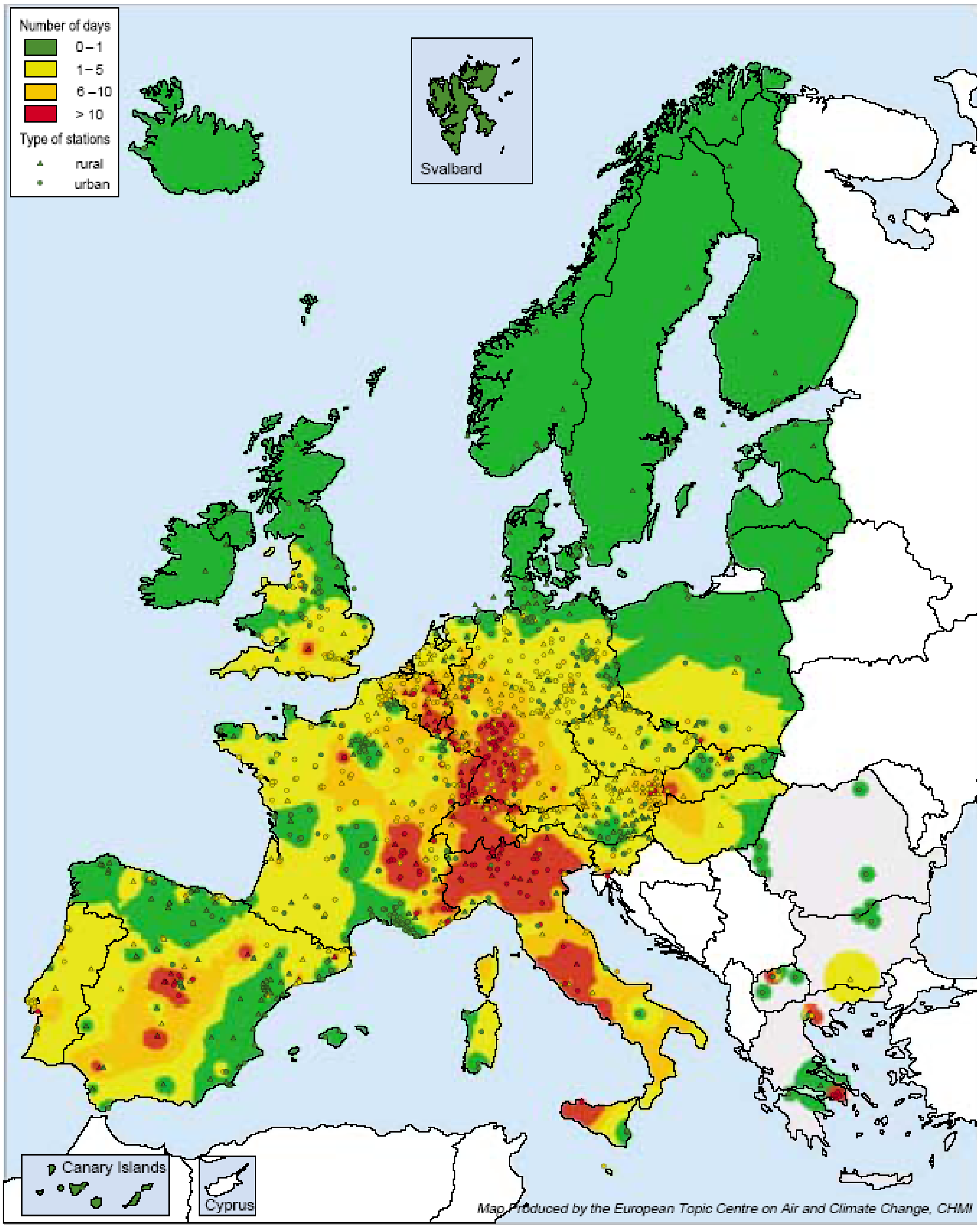
Figure 20 Percentage of people exposed to concentrations of ozone, PM_{10} and NO_2 over thresholds or limit values in Europe.

Figure 21 is a map, which illustrates the geographic distribution of the latest Ozone episodes.

In the period 1995–2003 of reporting under the old Ozone Directive there was little or no change in the reported exceedances of ozone threshold values (EEA, 2003b). This is not unexpected as reductions in the EU emissions of NO_x and NMVOC, the main ozone precursors, have so far been limited — about 30 % between 1990 and 2000. The threshold for warning the population continues to be exceeded on a few occasions each year, while the threshold for informing the population is exceeded at most stations in most countries (outside northern Europe and Ireland) each year, generally more so in warm summers. These exceedences are likely to recur in years with temperatures above the long-term average until there is a substantially larger decrease in precursor emissions. A further reduction of about 30 % is foreseen towards 2010 under the NEC Directive.

While peak ozone concentrations seem to go down, ozone concentration statistics relevant to the target values set in the new Ozone Directive show little or no reduction in the period 1996–2000. Very few stations actually show a significant downward trend for these statistics. Under current legislation and

with the rate of turnover of the vehicle fleet, further reductions will gradually occur towards 2010, and further reductions may be necessary to achieve the target values of the new Ozone Directive.
Note that these conclusions are tentative, due to the uncertainties caused by year-to-year meteorological variations and the changes in the number and distribution of monitoring stations included in reporting under the Ozone Directives.



Map Produced by the European Topic Centre on Air and Climate Change, CHMI

Figure 21 Exceedence of information threshold of ozone at 180 μg/m^3.

5.2. Costs

See paragraph 2.2.

5.3. Compliance/enforcement

See paragraph 2.3.

5.4. Administrative feasibility

The ozone problem requires international co-operation, as well as co-ordinated national measures.
The CLRTAP was not very efficiently transposed to national legislation, and there are no penalties except political pressure for not being in compliance with the agreements.
The EU directives have been transposed into national legislation, and penalty rules are included in some of the directives.

5.5. Political acceptability

See paragraph 2.5.

6. CONCLUSIONS AND POTENTIAL FOR EU FUTURE ACTIONS IN RELATION TO ACIDIFICATION, EUTROPHICATION AND GROUND LEVEL OZONE

The co-operation on abatement of regional air pollution (acidification, eutrophication and ground level ozone) in Europe has generally been a success, especially reduction of emissions of SO_2 and NO_x.

It has been difficult to assess the cost effectiveness of the European legislation and conventions, especially to separate the effect of specific rules and regulations. The regulatory framework for abating emissions has been characterised by significant uncertainty, increasing complexity and overlapping requirements. It included international obligations both as a member of the European Union and as a signatory to the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP).

Public awareness and political pressure has been very important for the possibility to develop national legislation. The national legislation has led to over compliance in several countries, especially for SO_2.
The most cost-effective measures has been based on scientifically sound assessments and when all important processes are known and well described. The role of sulphur emissions in acidification is a good example, where there is a close and linear relationship between emissions and ambient air quality and deposition. Eutrophication and especially ground-level ozone include more pollutants and complicated atmospheric processes, including also natural sources and relatively high background concentration of ozone on the Northern Hemisphere. There are still needs for development of better tools for assessment of this type of air pollution problem.

Some efforts to apply innovative economic instruments such as emission trading have been made in Europe, but it is still too early to assess the effect of this instrument. Other economic instruments such as taxes have been applied
.

CASE STUDY 1 – ANNEX III

THE US APPROACH TOWARDS ACIDIFICATION, EUTROPHICATION AND GROUND LEVEL OZONE

4 October 2004

1. ADDRESSING ACIDIFICATION AND EUTROPHICATION IN THE UNITED STATES

1.1. Introduction

National regulation of SO_2 and NO_2 began with the National Ambient Air Quality Standards (NAAQS) under the 1970 amendments to the Clean Air Act.[22] In addition, EPA promulgated SO_2 and NO_x New Source Performance Standards (NSPS) for new and modified power plants. Many sources realized that the most cost-effective means to meet the NAAQS was to increase the stack height in order to reduce emissions in the vicinity of the facility, and consequently a large number of tall stacks were built. This practice, encouraged by EPA, assisted the vast majority of urban areas in attaining the SO_2 and NO_x NAAQS by 1980, although continued emission of SO_2 and NO_x had worsened the acid rain problem. In response, the 1977 CAAA required that EPA address emissions from new coal-burning electricity generating units and prohibited the use of tall stacks for compliance. EPA followed with standards that required new power plants to remove potential SO_2 emissions from coal and operation at a set emissions rate. EPA also established New Source Review (NSR) permitting program to regulate new and newly modified power plants. US SO_2 emissions consequently started to steadily decline, yet these regulations were deemed unsuccessful because they had made new plants more costly and created an economic incentive for extending the life of older facilities. In part because of this disincentive, and in part due to the greater longevity of existing power generating units, the capital stock turnover envisioned by the Act did not occur as expected. Eventually, the 1990 CAAA established the latest set of air quality management requirements that included an Acid Rain Program with a successful emissions trading program.

1.2. Emissions Sources

In the US, a number of sources release SO_2, $NO_{x,}$ and NH_3 atmospheric emissions that contribute to acidification and eutrophication. Figure 1 shows the contributions from major emission sources in 1990, the year of the most recent amendments to the Clean Air Act. In 1990, stationary fuel combustion by power generators and industries was the dominant source of SO_2 emissions (88 percent) and a very significant source of NO_x emissions (43 percent). Specifically, the power sector accounted for 69 percent of US SO_2 emissions and 26 percent of NO_x, while fuel combustion at industrial sources accounted for 15 and 12 percent of SO_2 and NO_x emissions, respectively. The transportation sector was a dominant source of NO_x emissions, accounting for 53 percent of national emissions. Agriculture and forestry contributed most of the NH_3 emissions (87 percent), while chemical manufacturing sector and transportation sector accounted for 8 percent and 4 percent, respectively.

---

[22] See case study two for more discussion on NAAQS.

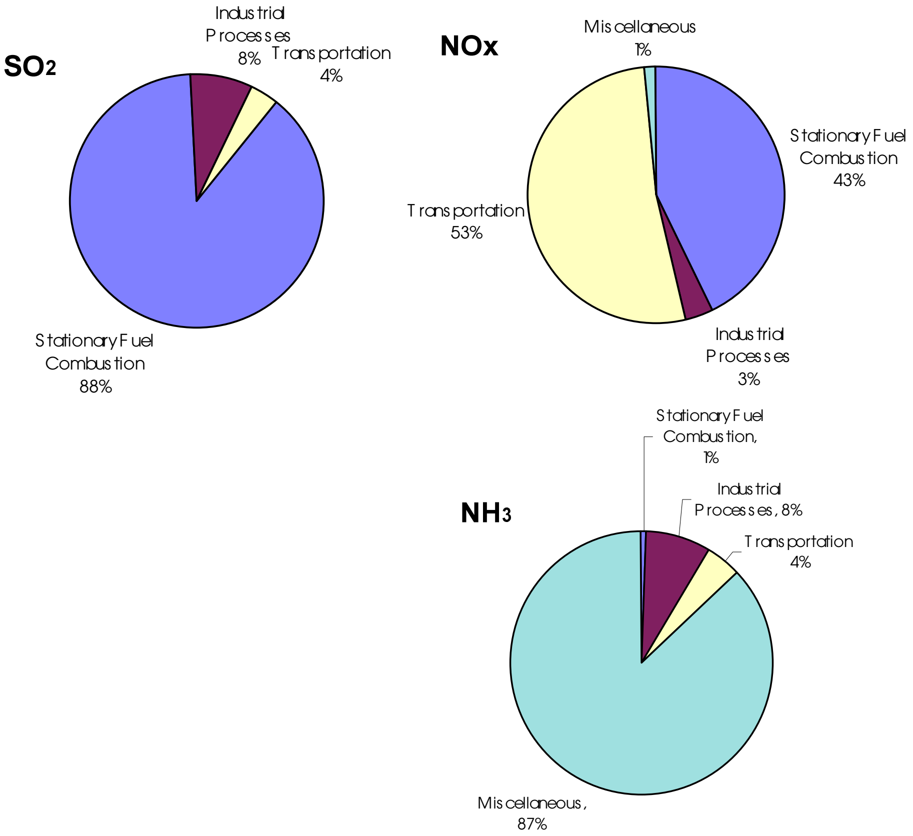


Figure 1. US national average SO_2, NO_x and NH_3 emission categories for 1990 (EPA, 2003b)

2. LEGISLATION AND MEASURES IMPLEMENTED

While many of the earlier regulations are still in effect, including NSPS and NSR, the major US control program addressing acidification today is Title IV of the Clean Air Act Amendments (CAAA) of 1990 which focuses on reducing SO_2 and NO_x emissions from power plants.[23] Title IV, the Acid Rain Program, differs from earlier approaches in the use of emissions trading and its objective to address regional transport of emissions that contribute to downwind acidification. The NO_x acid rain control program has been implemented alongside a set of parallel requirements addressing NO_x emissions contributing to local ozone nonattainment. The acid rain requirements were the only ones to comprehensively address NO_x emissions coming from the Midwest, whereas both acid rain and ozone provisions affected plants in the Northeast. In instances where both sets of rules applied, the ozone standards were earlier and therefore controlling.

In addition to the Acid Rain Program targeting the power sector, SO_2 and NO_x from industrial sources such as smelters and sulphuric acid manufacturing plants are controlled through permits and technology-based performance standards.[24] EPA and many states also have standards and certification programs for residential and commercial burners. Additional emissions reductions from industrial, commercial and institutional boilers are expected as a result of EPA's new rule limiting air toxics from

---

[23] The scientific evidence at the time suggested that SO_2 was the largest contributor; therefore, the focus of the program was on control of SO_2.

[24] New-source review (NSR) and prevention of significant deterioration (PSD) are used for new sources or major modifications of existing sources while reasonably available control technology (RACT) and best available retrofit technology (BART) standards are used for existing facilities. For details, see NRC (2004).

these sources.[25] Going forward, regulations addressing regional haze, fine particles and the new ozone standard will contribute to additional reductions in SO_2 and NO_x emissions from a variety of sectors.[26] Programs to address these emissions from the power sector are currently being developed through the federal rulemaking process. Below we discuss the key elements of the current US efforts to control acidification by considering the separate efforts to control SO_2 and NO_x emissions related to acidification.

There has been little attention to regulated atmospheric emission contributing to eutrophication in the US. Nevertheless, regulations addressing acidification and ground level ozone have produced co-benefits of reduced atmospheric nitrogen inputs to watersheds, and such efforts that indirectly address eutrophication are discussed in this paper as well.

2.1. Acidification

2.1.1. Controlling SO_2 Emissions

Title IV of the CAAA of 1990 set a goal of reducing annual SO_2 emissions by 10 million tons below 1980 levels. To achieve these reductions, the CAAA established a new emissions trading system to reduce emissions of SO_2 from fossil-fuel burning power plants located in the continental 48 states of the US. The program consisted of two phases. Phase I, from 1995 to 1999, covered 263 electric generating units larger than 100 MW with an annual average emission rate in 1985 greater than 3,4 kilograms of SO_2 per kJ of heat input.[27] Emissions caps for these Phase I units were provided in the Act. In Phase II, beginning in 2000, additional plants having generating units larger than 25 MW were added to the program. Phase II limited emissions to an annual cap of 8,12 million tonnes, equivalent to an average emission rate of 0,98 kg/kJ, when divided by the mid-1980s level of heat input at fossil-fuel burning power plants. This cap level is about half of the total electric utility SO_2 emissions in the early 1980s. Additionally, Phase II generating units had the option of opting-in to the allowance market in Phase I, and industrial units emitting SO_2 had the option of participating in the trading program, starting either in phase one or phase two.

Caps on emissions were implemented by issuing tradable allowances that in total equalled the annual cap level. To comply, sources were required to surrender one allowance for each ton of emissions. A source that had more allowances than it needed to cover its emissions could sell the excess allowances, and sources that required additional allowances to cover emissions could purchase allowances to cover the gap. Allowances not used in the year they are issued could be banked for future use. Most of the allowances were issued to sources on the basis of each unit's average annual heat input during the three-year baseline period, 1985 to 1987, multiplied by their specified emissions rate, which in turn depended on the plant category. In all, each of 35 different types of plants received allowances based on a different formula. A small share (2,8 percent) of allowances was sold through an annual auction conducted by EPA to ensure the availability of allowances for new generating units. The revenues from these sales were returned on a pro rata basis to the owners from whose allocations the allowances were withheld. In addition, 3,5 million bonus allowances were awarded to plants that utilized scrubbers to achieve compliance and 300.000 bonus allowances were available to utilities that either installed renewable generation facilities or implemented demand-side energy conservation programs to reduce emissions. Allowance distribution for Phase I units was specified in the Act.

The trading program relied on emissions monitoring equipment and tracking provisions. All participating units were required to use continuous emissions monitoring systems (CEMS) or an

---

[25] EPA estimates SO_2 reductions between 44 and 103 kilo tonnes per year in the fifth year after promulgation. (EPA, 2004a)

[26] For more details on these efforts, see discussions on ground level ozone and case study #4 on particulate matter.

[27] The US uses pounds of pollutant per mmBtu of heat input (lbs/mmBtu), which is converted to kg/kJ in this paper.

approved alternative measurement method, which are reviewed for accuracy and reliability. These systems report hourly emissions electronically and these data are verified and recorded by EPA. The data is made available on the internet to ensure program transparency. At the end of the year, compliance is demonstrated by comparing each unit's allowances to the unit's annual SO_2 emissions.[28] Units with too few allowances are subject to two penalties: (1) a fine of US$3,06 per excess kg of emissions in year 2001 dollars[29] and (2) a requirement to offset the excess emissions with an equivalent number of allowances.

The SO_2 Acid Rain trading system was implemented on schedule. An allowance market emerged by mid-1994 and significant amount of trading took place: between 8 and 30 million allowances were transferred annually from 1994 and 2001, with some growth in the total allowances transferred and the total transfers between economically distinct entities (Ellerman, 2003b).[30] In addition to the 263 power generators required to comply with the first phase of the Acid Rain Program, over 200 electric utility generators and a few other industrial sources not subject to Phase I opted to voluntarily participate in the first phase and helped to lower compliance costs for units subject to Phase I. While industrial sources also had the option of opting in to the program, they had little incentive to change from a rate-based emission limit to an overall cap that could restrict future growth. As a result, a very small number of industrial sources opted in to the program.

Because participation by Phase II and industrial units was voluntary, only those with emissions below the pre-set emissions baseline and that were not expecting to increase capacity opted to participate, creating "anyway tons" amounting to 3 percent of the Phase I allocation. Some of these units may have reduced emissions further based on marginal compliance costs. In Ellerman's view, this voluntary opt-in program "cannot be said to have threatened the overall integrity of the SO_2 cap" and did not result in significant environmental damage (2003b:26). On the other hand, the measure was not important in reducing program costs. On balance, Ellerman concludes, the voluntary opt-in program was "not worth the extra administrative effort" (2003b:26).

While the SO_2 acid rain trading program achieved near-100 percent compliance (discussed below), there were some early glitches in the data reporting systems. Specifically, in the first several years of the program, EPA staff identified errors, miscalculations, and oversights in monitoring and reporting systems. In 2003, a new electronic audit system was deployed that will automatically identify data issues requiring additional staff verification.

2.1.2. Controlling NO_x Emissions

In addition to the trading program for SO_2, Title IV of the Clean Air Act Amendments establishes annual NO_x emission rate limitations to address the contributions of upwind coal-fired power plants to acidification. Different emission rate limits were established for different types of coal-fired boilers, implemented in two phases. The standard emission limit ranges from 0,19 to 0,21 kg/kJ for tangentially-fired boilers under the different program phases to 0,41 kg/kJ for cyclone boilers. These limits were based on installation of low-NO_x burners, a technology that was well understood. At the time, SCR technology was deemed to be too costly.

To comply with the NO_x limits, sources have the option of using emissions averaging, in which a company meets its emissions reduction requirements by choosing to make a group of NO_x affected boilers subject to a group NO_x limit using a energy-weighted rate. In Phase I, a utility can also petition for a less stringent Alternative Emission Limit (AEL) if it properly installs and operates the NO_x emissions reduction technology prescribed for that boiler type but is unable to meet its standard limit.

---

[28] Utilities are granted a 60-day grace period to purchase additional allowances to cover their emissions for the year.

[29] The fine was initially established as US$2000 in 1990, which is adjusted for inflation to estimate the current fine.

[30] Many early trades occurred within a given company.

A further option available to companies, Early Election compliance, allowed companies to include units in the first phase compliance period that were not subject to regulation until the second phase. This allowed companies to take advantage of least cost reduction options from their full range of units. Overall, these emission limits sought to reduce emissions by 1.8 million tonnes below 1980 levels by 2000. Table 1 shows the number of units by type involved in the system and their emissions rate.

Table 1: Title IV NO_x standards by boiler type (EPA, 2003b)

Boiler Type	Phase 1		Phase 2	
	# of units	Standard (kg/kJ)	# of units	Standard (kg/kJ)
Tangentially-fired	135	0,21	306	0,19
Dry bottom wall-fired	130	0,24	312	0,22
Cell burners			37	0,33
Cyclones (>155 MW)			56	0,41
Vertically fired			28	0,40
Wet-bottom (>65 MW)			31	0,40

2.2. Eutrophication

Despite the evidence that nitrate and ammonium deposition is a major source of nutrients and associated eutrophication of estuaries, the US has not yet established a regulatory approach that directly addresses eutrophication problems. Even though a number of monitoring networks currently exists for atmospheric nitrogen deposition to estuaries, they do not track dry gaseous NH_3 deposition (NRC, 2004). In fact, eutrophication has not received adequate attention in the implementation of the Clean Air Act, which focused on addressing other problems such as ozone, acid rain, haze and fine particulates. As a result, addressing eutrophication of estuaries has been considered as a co-benefit of reducing NO_x emissions for ozone, as shown in the benefit analysis of the regulatory impact assessment of NO_x SIP Plan, discussed later (EPA, 1999a).

Besides, the current US water management system under the Clean Water Act's total maximum daily loads (TMDLs) for nutrient-impaired water bodies is focused on regulating point and nonpoint sources of effluent (e.g. waste water treatment plants and agricultural runoff) rather than sources of atmospheric emissions. In a few instances, States have developed goals for specific watersheds that could potentially include a role for air sources of nitrogen emissions. For example, in 1987, the Governors of Maryland, Virginia and Pennsylvania, and the Mayor of DC, signed the Chesapeake Bay Agreement requiring 40 percent reductions in the controllable fraction of nutrients reaching the Chesapeake Bay by the year 2000. However, there has been no progress in developing a clear mechanism to compel emission reductions beyond what would be achieved by the Clean Air Act for other purposes, even though NO_x emissions contribute up to 35 percent of total controllable nitrate loads in the Chesapeake Bay.

At this time, research institutions and government agencies are actively engaged in understanding the effects of atmospheric nitrogen (and mercury) deposition in estuaries. EPA is also battling with technical issues of determining how to integrate air and water modelling results, identifying sources or types of sources contributing to air deposition in a water body, and approaches for taking into account technical uncertainties and data limitations (EPA, 2001). In addition to conducting a few pilot studies to investigate deposition of nitrates, ammonium and mercury, EPA is currently putting together its first official guideline for NH_3 emissions inventory. States are also required to report NH_3 emissions data for the first time in 2004. These efforts will hopefully provide insights regarding the development of management strategies for atmospheric emission sources for nitrogen and provide an impetus to major sources to make voluntary emissions reductions (EPA, 2001).

3. ASSESSMENT OF THE EFFECTIVENESS

Below we discuss the effectiveness of the US acid rain effort by considering the environmental effectiveness, costs, compliance and enforcement, administrative feasibility, and political acceptability.

3.1. Environmental Effectiveness

To evaluate the environmental effectiveness of this effort, we first consider the resulting emissions reductions and then consider the effect on impacts, namely acidification levels.

3.1.1. Emissions

Since the US program had separate efforts and mechanisms for SO_2 and NO_x, it is useful to consider the resulting emissions reductions separately, although there is significant overlap as compliance with one component can impact emissions of the other pollutant.

3.1.1.1. SO_2

Power sector SO_2 emissions have declined from 14.2 million tonnes in 1990 to 9.3 million tonnes in 2002, a 35 percent reduction as a result of the acid rain trading program (EPA, 2003a). SO_2 emissions from other point sources also declined in this timeframe, resulting in an overall 31 percent total reduction in SO_2 emissions between 1993 and 2002 (EPA, 2003a). Emissions have continuously declined over time, and are well below what is required under the Acid Rain Trading Program.

SO_2 emissions trends for Phase I (blue area) and Phase II (white area) sources covered under the Acid Rain Trading program are shown in figure 2. Starting in Phase II, SO_2 emissions from the power sector have been greater than the total allocation due to the popularity of emissions banking as a compliance strategy. The difference between emissions from the covered sources (blue area prior to 2000 and yellow area starting in 2000) and the amount allocated (the red dashed line) shows the amount of banking during Phase I and what has been drawn from the bank during Phase II.

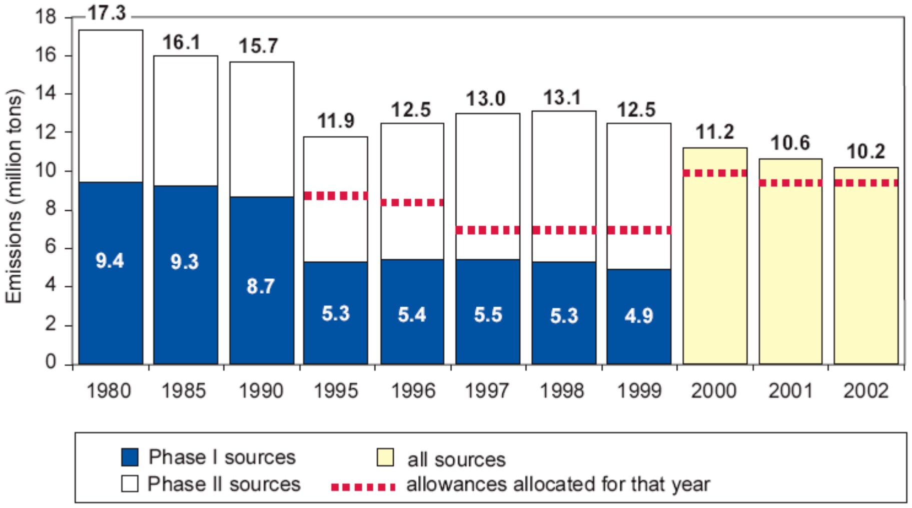


Figure 2. SO_2 emissions from electric utilities in the United States from 1980 to 2002 (EPA, 2003a)

The emissions banking provisions of the Acid Rain Trading Program have resulted in significant levels of early emissions reductions and, therefore, greater cumulative emissions reductions than would otherwise have occurred. Ellerman (2003b) compared the actual Title IV experience with a counterfactual scenario in which source-specific limits are applied to power plants equal to the allowance allocations under Title IV. In terms of overall emissions reductions, measured as cumulative emissions, Title IV fared better than the counterfactual scenario largely due to the role of emissions banking. In this analysis, 30,6 million tonnes of SO_2 have been reduced under the Title IV program between 1995 and 2001, 29 percent more than the estimated 23,7 million tonnes that would have been reduced under a counterfactual scenario without banking (Ellerman, 2003b:19). Burtraw and Mansur (2003) also found that banking induced lower emissions in early years of the program and higher emissions in later years of the program. Using an integrated assessment computer model, the Tracking and Analysis Framework, Burtraw and Mansur (2003) found reduction of sulphate deposition in every state in the 1995 timeframe, and concluded that with such early actions, banking expedites the time of ecological recovery to the extent that threshold and acute effects do not occur.

However, banking can also pose problems. At the end of 2001, this bank totalled 9.30 million allowances, a level roughly equivalent to the total annual allowances available to all sources (9.54 million). There are various conditions that could result in faster annual use of banked allowances, leading to year-to-year growth in emissions. Some of these conditions could include significant increases in natural gas prices, and establishment of new, more stringent requirements for SO_2 that do not give value to previously banked allowances from the acid rain trading program.

In addition to the significant SO_2 reductions achieved, it should be noted that these reductions were accomplished relatively quickly. Emissions reductions from Phase I sources of 3,1 million tonnes were achieved in the fifth year following passage of the enabling legislation. Explanations for this quick progress include the absence of lawsuits and the relatively modest implementation requirements associated with the trading program compared with the traditional US command-and-control approach to regulation.

While overall US national SO_2 emissions have declined substantially over the last decade, concerns have been raised about the potential for “hotspots.” Under a cap-and-trade system, it is possible that while overall emissions are reduced to the cap level, emissions from some plants could remain constant or even increase, consequently creating hotspots. Several studies dispute the notion that the Acid Rain Program created hotspots. Swift (2000) found that emissions were below allotted levels in nearly all states (slight increases in MA, MS and IL) and in the three major power producing regions (Mid Atlantic, Midwest, Southeast) during the first four years of the program. Birnbaum (2001) also confirmed no significant regional emission shifts or in-flows; indeed, the greatest emission reductions had occurred in the high emitting Midwestern states where the cost per ton reduction was the lowest. To the extent that power plants in this region had been creating local hot spots, emissions trading may be accountable for cooling hot spots. Similarly, concerns about potential environmental justice issues with the emissions trading program were also resolved. Corburn (2001) found no strong evidence suggesting that SO_2 emissions from Phase I power plants were disproportionately concentrated in the poor communities of colour.

Several recent promulgated regulations—the Tier II, Heavy Duty Diesel, and Nonroad Diesel—or proposed rules—such as the Interstate Air Quality Rule—are expected to further reduce US SO_2 emissions in the coming years (see Figure 3). More details on the Tier II, Heavy Duty Diesel, and Nonroad Diesel rules are provided in case study 4. More details on the proposed Interstate Air Quality Rule is provided under ozone control later in this section.

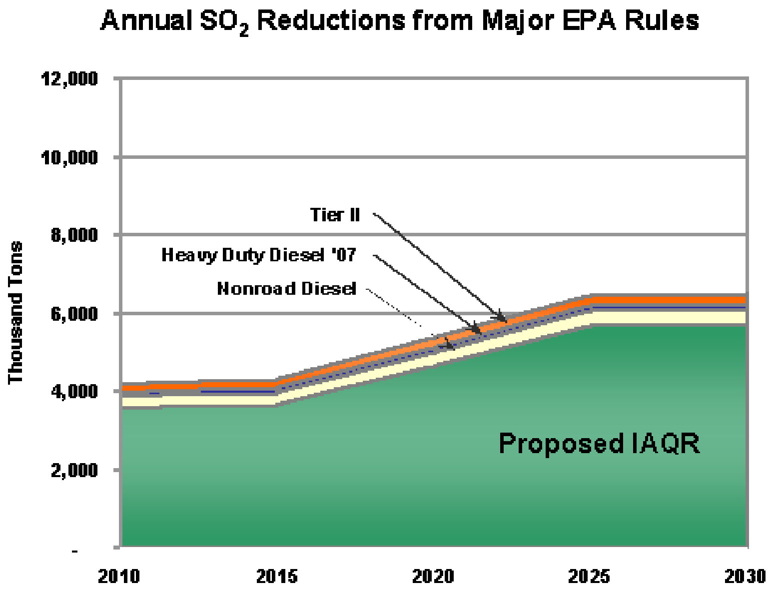
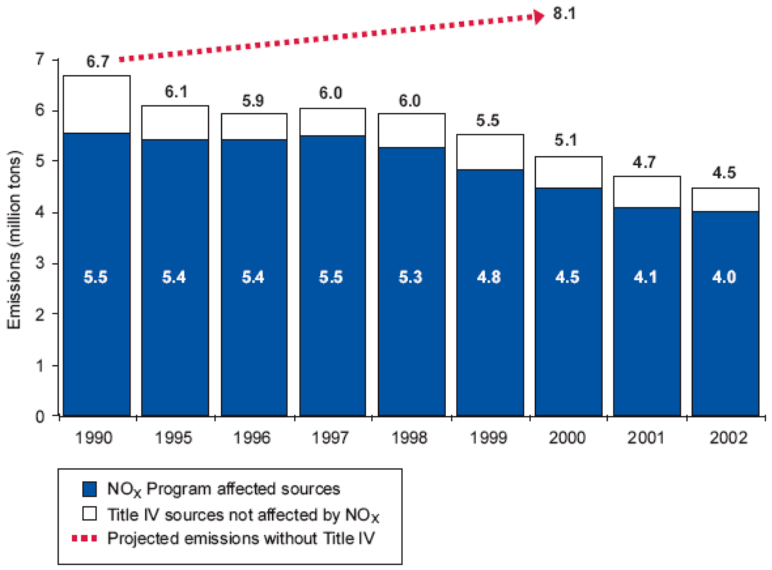


Figure 3. Annual SO_2 emissions reductions from Major EPA Rules (EPA, 2004h)

3.1.1.2. NO_x

NO_x emissions from the power sector were reduced from affected Title IV sources from about 5,0 million tonnes in 1990 to about 3,6 million tonnes in 2002, achieving a 27 percent reduction (EPA, 2003b). Title IV can take partial credit for this achievement, along with the various measures designed to address ozone pollution including New Source Performance Standards, discussed later. Initially, the performance objective for the NO_x program had been to achieve and maintain a 1,8 million tonne reduction from these sources relative to the NO_x emission levels projected to occur in 2002 absent the Acid Rain Program. EPA (2003a) had expected, ex ante, NO_x emissions would increase by 1.3 million tonnes between 1990 and 2002 in the absence of Title IV (see Figure 4). In 2000, total NO_x emissions from affected units had been reduced to 4.1 million tonnes, 2.2 million tonnes below the ex ante projection without the Acid Rain Program. These reductions have been achieved despite rising power generation [31] from coal-fired power plants. However, without further reductions in emissions rates or establishment of a cap on NO_x emissions, national emissions may rise with increased use of fossil fuels in some areas of the country (EPA, 2003a).



---

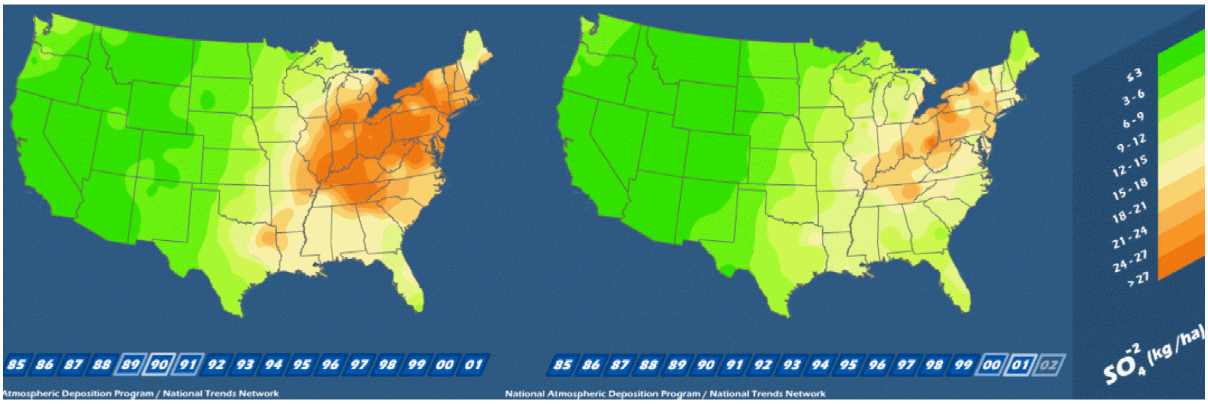
[31] Electricity generation from coal-fired power plants grew by 16 percent between 1990 and 2001.

Figure 4. NO_x emissions from acid rain sources, 1990 through 2002 (EPA, 2003a).

3.1.2. Environmental Impacts

The emission reductions achieved have led to observed reductions in acid deposition, the beginnings of recovery from acidification in fresh water, and improvements in visibility (EPA, 2003). Monitoring networks show that the decline in SO_2 emissions from power plants has reduced wet sulphur deposition and improved ambient concentration of sulphate. On the other hand, the decline in NO_x emissions has not been as large and consequently ambient nitrate concentrations and wet nitrate deposition have generally remained the same or increased in some regions (See Figure 5).

Wet Sulphate Deposition



Wet Nitrate Deposition

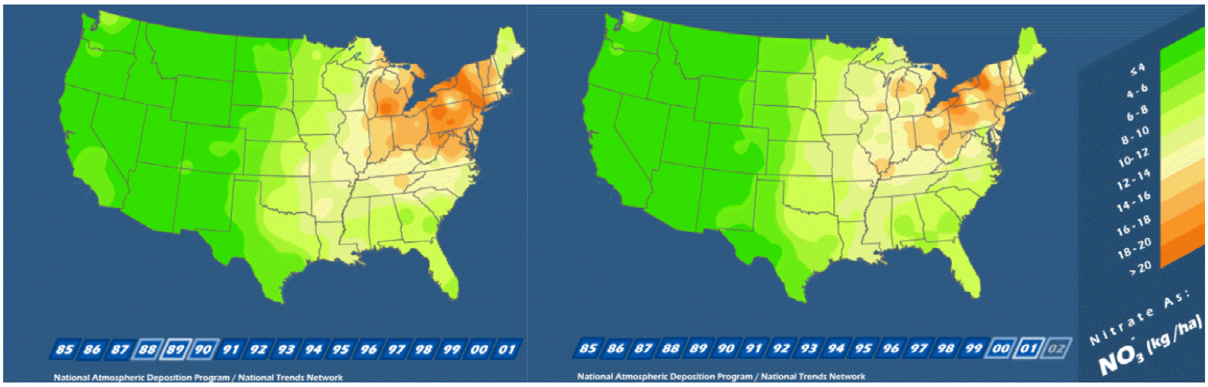


Figure 5: Trends in wet sulphate and nitrate deposition following implementation of Phase I of the Acid Rain Program: 1989-1991 vs. 2000-2002 (NADP, 2004)

According to EPA's Acid Rain Program progress report (2003a:8-13):

- Atmospheric SO_2 concentrations have decreased since 1990: concentrations in the Northeast and Mid-Atlantic were 6-12 µg/m^3 in 2002, as much as 8 µg/m^3 lower than in 1990. Atmospheric sulphate concentrations have also decreased: in 2002, concentrations in most of the East were 3-5 µg/m^3, as much as 4 µg/m^3 lower than in 1990.
- Wet sulphate deposition has decreased significantly since 1990: in 2002, deposition in most of the Northeast and Midwest was 10 to 20 kg/ha/yr, as much as 12 kg/ha/yr lower than in 1990. Some of the greatest reductions occurred in the Mid-Appalachian region, including Maryland, New York, West Virginia, Virginia and most of Pennsylvania. A strong, near linear correlation

between large-scale SO_2 emissions reductions and large reductions in sulphate concentrations in precipitation has been noted for the Northeast, one of the areas most affected by acid deposition.

- Wet nitrate concentrations across the US have generally remained the same, or increased in some regions. Even though wet nitration deposition does appear to be substantially lower in 2000 through 2002 (Figure 4), the decreases appear related to lower precipitation levels over these years. In fact, there are no observable broad-scale reductions in total wet and dry nitrogen deposition in the US since 1989.

Ultimately, however, the extent to which the acid rain control program can be judged a success depends on when and whether improvements are seen in sensitive lakes and forests. At this point, reductions in sulphur deposition have only begun to translate into improvements in water quality and forest health, and such translation remains fairly weak. In 2001, Driscoll and his colleagues (2001) suggested that sensitive areas such as the Adirondack region of New York were not recovering from the long-term exposure of acid deposition because of the diminished ability of the affected soils to neutralize inputs of strong acids. More recent research suggests there have been some improvements in the acid-base status of surface waters in acid-sensitive regions (NRC, 2004) and in the acid neutralizing capacity of the soils (Ellerman, 2003b). To achieve recovery of sensitive ecosystems in the next 20 to 25 years, greater SO_2 reductions on the order of 80 percent beyond the phase II cap and additional NO_x reductions are needed (Driscoll et al, 2001). Improvements in coordinated monitoring and tracking systems for soil-chemistry perturbations induced by acid precipitation and air pollution impacts on forested ecosystems would be useful as well (NRC, 2004).

3.2. Costs

3.2.1. Cost-effectiveness

Investigators differ on the relative cost-effectiveness of the acid rain control program. In part, results depend on whether one compares the effects with the ex ante projected costs of an SO_2 control program or the likely costs of a non-trading scenario that factors in the effects of various exogenous changes that took place unrelated to the establishment of the Acid Rain Trading program. One way to consider the impact is to evaluate ex ante cost estimates for the fully phased-in Acid Rain Trading program, assuming compliance with a traditional technology-based program requiring scrubbers at all units, which was the alternative under consideration in 1990. While estimated costs of the alternative technology-based program range from \$3.5 to \$7.5 billion per year, current estimated costs of Acid Rain Program by 2010 are just over \$1 billion per year (Ellerman, 2003b).[32] Greater flexibility in the compliance methods of the emissions trading system is considered to be the biggest cost-saving factor by allowing affected sources to choose the lowest-cost pollution abatement methods, ranging from end-of-pipe scrubber technology, to fuel switching to low sulphur coals, to dispatch changes, or to purchase of allowances from other sources.

While there is no question that the Acid Rain Trading program achieved significant cost savings over what was predicted ex ante, there is some disagreement over the degree to which the emissions trading mechanism was responsible for these savings. Two groups of investigators (Carlson et al., 2000; Ellerman, 2003b) sought to understand the cost savings associated with the Acid Rain Trading system versus a fictional mandatory compliance regime that allows for flexibility in meeting a given emission rate target. Carlson and his colleagues (2000) estimated that the actual cost of complying with Title IV in 1995 and 1996 was \$30 to \$130 million more than the cost of a benign command-and-control alternative, and significantly greater than the estimated cost of a fully efficient trading program. In contrast, Ellerman (2003b) estimated that cost savings of \$350 million per year have been realized in the early years of Phase I. One possible explanation for the differences in these estimates relates to

---

[32] Ex ante estimates of the cost of a trading system were also significantly higher than actual costs, from \$2,3 to \$6,0 billion.

assumptions about power markets. While Carlson and his colleagues (2000) assumed that power plants were restricted from making efficient decisions because of the regulated power markets, Ellerman (2003b) assumed that state power markets had insignificant influence on allowance trading activities. Carlson added that the sub-par performance of trading of the Acid Rain Trading Program is a result of technological advances that reduced the differences in marginal costs of compliance, thereby reducing the potential gains from trade. In any case, lower than expected level of trading in early years of the program has increased in subsequent years, indicating greater gains from trading as more sources entered the trading system.

The cost-effectiveness analyses also credit the trading system for increasing availability and lowering the cost of low-sulphur coal, as well as lowering power demand, all of which were unexpected benefits. In fact, Carlson and his colleagues (2000) suggested that 80 percent of the reduction in cost is attributable to falling price of low-sulphur coal relative to the price of high sulphur coal, while the remaining 20 percent is due to technology change. In particular, falling coal prices attributed to rail deregulation, which consequently reduced the Phase I abatement cost by 50 percent for generators that switched from high to low sulphur coals (Ellerman and Montero, 1998).

Another indicator of the program cost-efficiency is the allowance price. Allowance prices ranged from a low of \$70 per tonne in early 1996 to highs slightly above \$220 per tonne in 1999 and 2001. Current prices are approaching \$440 per tonne due to market expectations for tighter future requirements (Air Daily, June 18, 2004). A significant level of allowance banking helped smooth the transition between Phase I and Phase II. Units went from banking 1,6 million tonnes in 1999 to drawing down the bank by 1,36 million tonnes in 2000. In fact, recent research by Ellerman and Montero (2002) confirms that in the aggregate, banking has been surprisingly optimal from an efficiency standpoint.

While there was no national trading system for NO_x, Title IV requirements provided a significant degree of compliance flexibility, including the ability to average across a company. As a result, lower cost options than initially anticipated were used.

3.2.2. Costs and Benefits

According to a study by the US Office of Management and Budget (2003) covering the early years of the Acid Rain Trading program, the annual benefits of acid rain SO_2 regulations (\$78 to \$79 billion USD) far exceeded the costs (\$1 to \$2 billion USD). Similarly, acid rain NO_x regulations resulted in annual benefits of \$1 to \$5 billion USD and costs of \$372 million USD. Most of the benefits are due to health benefits from reducing ambient levels of fine particulate matter (OMB, 2003).[33]

In terms of the broader welfare effects from the tax and regulatory interactions resulting from the treatment of abatement costs and the scarcity rents generated by the environmental constraint, Title IV did not achieve full economic efficiency because 1) allowances were not auctioned and the proceeds were not used to reduce distortionary taxes on labour and capital, and 2) the average cost rules applying to units remaining under public utility cost-of-service regulation prevent the full marginal cost of abatement from being passed on to customers in the price of electricity (Ellerman, 2003b: 7-8). However, recent analysis suggests that the way allowances for SO_2 and NO_x are distributed initially does not matter in an important way to economic efficiency (Palmer et al., 2003).

3.2.3. Technological innovation and improvement

A significant amount of technological progress occurred with implementation of the Title IV, although it is difficult to discern the degree of similar progress that would have occurred under a command-and-control regulatory system. Nevertheless, greater use of low sulphur fuels and application of scrubber technology was achieved under the Acid Rain Program. Greater availability of low sulphur fuel from the western US to eastern power plants was largely due to simultaneous deregulation of the rail

---

[33] Acid Rain Program reduces SO_2 and NO_x that are precursor pollutants that contribute to the formation of secondary fine PM.

industry that lowered the transportation portion of the fuel cost. Paired with greater flexibility of choosing compliance methods, eastern power plants were encouraged to experiment with the level of blended fuel that can be used without resulting in a significant derate of the generating plant.

In addition, the costs of scrubber technology in Phase I came down versus the ex ante predictions, from a total cost of $0.51 per kg to $0.32 per kg. The decrease in cost was largely due to: (1) reductions in the fixed and variable operation and maintenance costs from improved instrumentation and control; (2) reductions in the parasitic loss of power and manpower requirements; and (2) a 25 percent increase in the utilization of scrubbed plants (Popp, 2001). This higher utilization of scrubbed plants was induced from scrubber operating costs that were lower than allowance costs, since plants switching to low-sulphur coals faced a premium fuel cost over the scrubbed plants burning higher-sulphur coals. Based on recent scrubber installations and allowance prices, control costs appear to be coming down further as we enter the second phase of the trading program (Ellerman, 2003a). However, similar to the cost-effective analyses, the degree to which emissions trading system encourages technology innovation versus under command-and-control approaches is not universally agreed. With the passage of the 1990 CAAA, there has been a decline in patent activity, while removal efficiency that had previously remained constant has improved significantly (Popp, 2001). The verdict is still out on the degree to which technology innovation was spurred by Title IV as opposed to plants taking advantage of known technologies in their compliance.

Compliance with the NO_x emission limits was largely met through installation of low-NO_x burners, which was a widely available technology prior to regulation. Of the 265 coal-fired units under Phase I, 175 met the required limits, or in the case of some cyclone and cell burners, applied for and received Alternative Emission Limits, upon installation of low-NO_x burners (Burtraw and Evans, 2003). The remaining units optimized their boilers by adjusting air/fuel mixtures and temperatures or modified their boilers in a way that lowered temperature but incurred a slight heat rate penalty. In fact, there was little incentive to take the financial and compliance risks needed to innovate and find more effective and cost-effective approaches, because the regulations were not only passive but also allowed for a high degree of compliance flexibility, including failure. Regulated power markets also enabled most power plants to pass through the added costs of control technology to their rate base (Burtraw and Evans, 2003).

3.3. Compliance and Enforcement

The transparent system of the Acid Rain Program in which non-compliance and penalties are well understood led to a near-perfect record of compliance. Because all participating units must have working CEMs, there is no question as to the number of allowances that are needed for compliance. A known, significant (roughly ten times greater than the cost of allowances), and automatic economic penalty also encouraged compliance. Transparency and flexibility of the program also allowed little basis for regulated sources to sue or delay compliance. As a result, it became less expensive for firms to comply with the requirements than to avoid compliance by seeking the various forms of modifications that characterize traditional regulatory programs such as exemptions, exceptions, or relaxations of the program's requirements (Ellerman, 2003b). As a result, with the exception of a few very small failures, all power plants have been in compliance with Title IV SO_2 allowance trading requirements in all years (Ellerman 2003b; EPA, 2003a). This near-100 percent compliance is extremely different from command-and-control systems that often grant delays or relaxed requirements to sources that are unable to meet the standards (but are not able to compel over-compliance at other sources to compensate for the resulting emissions increases).

In fact, if anything, sources in the Acid Rain Program have over-complied with the emission reduction requirements. As mentioned above, units that have over complied in a given year can bank their excess allowances for use in later years. At the end of 1999, the end of Phase I, the amount of banked allowances totalled 10,75 million tonnes (Ellerman, 2003a; 2003b). As Phase II commenced, the quantity of allowances held in the bank declined as some units began to apply their banked allowances towards their Phase II caps. As of March 2003, over 8,5 million banked allowances were held in accounts, shown in Figure 6 (EPA, 2003a).

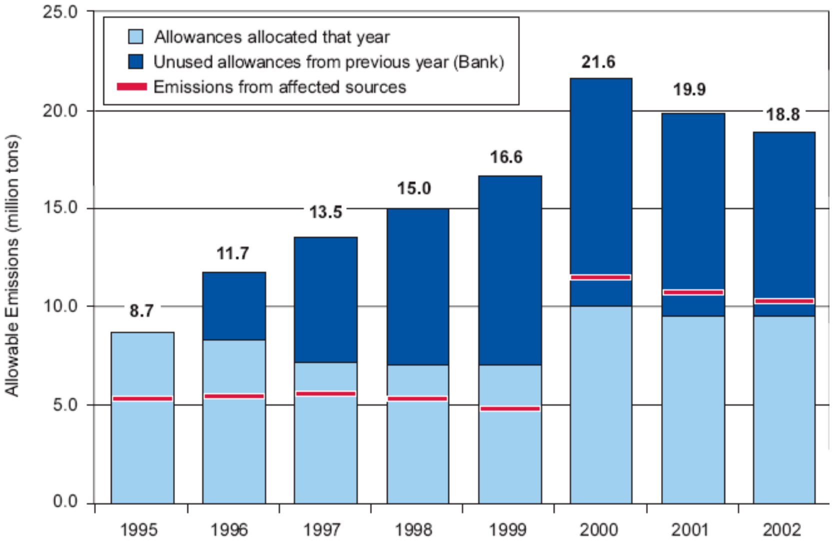


Figure 6. SO_2 Allowance Bank from 1995 through 2002 (EPA, 2003a).

In the case of Title IV NOx reduction program, the data show that nearly all units were in compliance in each year, with emissions averaging the preferred option. The table below displays the compliance options chosen and the respective number of units for each year from 1996 through 2002. In the first four years of the program, all sources were in compliance, and in subsequent years, just one source each year did not comply. In 2002, for example, one source had excess NO_x emissions of 42,6 tonnes and was assessed a monetary penalty of $134.000. However, while nearly all sources were technically in compliance, a small share of sources (1,7 to 3,8 percent of affected units each year) applied for and received permission to use an alternative (weaker) emission limit in cases where the low NO_x burner control technology did not perform as well as expected. This had the effect of increasing NO_x emissions, but the overall impact was negligible. For example, in 2000, 22[34] units exceeded the standard limit, increasing NO_x emissions by about 27.216 tonnes over the level that would have been expected had these units met the standard limit. This increase represents less than 1 percent of emissions from affected units (4,1 million tonnes).

Table 2: Title IV NO_x program compliance (# of units)

Option	1996	1997	1998	1999	2000	2001	2002
Affected Units*	**239**	**265**	**265**	**265**	**1046**	**1046**	**1048**
In compliance	**239**	**263**	**265**	**265**	**1045**	**1045**	**1047**
Standard Limit	46	53	51	51	133	140	150
Emissions Averaging	189	204	204	204	645	638	631
AEL (Low NO_x Burner)	4	7	10	10	27	27	26
Conditionally in Compliance**		**2**					
Not in Compliance	**0**	**0**	**0**	**0**	**1**	**1**	**1**
Units Granted Extension	**27**	**1**					
SO_2 Scrubber	24						
Timing	3	1					
Early Election Units		**272**	**275**	**274**	**274**	**274**	**273**
In Compliance		270	275	274	274	274	273
Pending		2					

---

[34] Note that in 2000, 5 units that received AELs met the standard limit.

---

*Annual totals from 2000 – 2002 do not sum because some affected units included in emissions averaging compliance were also required to meet AEL or Early Election Units.
**Units with AEL petitions pending.

3.4. Administrative Feasibility

In theory, emissions trading programs such as the SO_2 provisions under Title IV require greater up-front design efforts versus command-and-control approaches, but a smaller government role in implementation. In addition, the required administrative tasks differ across the two approaches. Instead of the inspection and enforcement role that is typical under a command-and-control regime, under cap-and-trade, the government role largely shifts to ensuring that CEMs are in working order and managing the data. Actual costs to EPA to implement the Acid Rain Program during the five years following the Clean Air Act Amendments came to $44 million, or 4 percent of total costs to implement the Clean Air Act in the same period (NCEE, 2001). According to EPA, the number of people involved in administering the Acid Rain Trading program is a third of what would be required for a more conventional air emission control program.

3.5. Political Acceptability

Use of a trading system for SO_2 emissions to address acid rain has received widespread support and acceptance from a diversity of stakeholders, including industry, governments and many national and state environmental organizations. Most of these stakeholders recognize the success of the acid rain trading program in substantially reducing emissions without creating hotspots, and are now more open to use of emissions trading to address future pollutants. Note that support for emissions trading from the environmental community and certain other stakeholders depends on the specific context and the program design. In particular, while there is reasonable comfort in using emissions trading to address non-toxic air pollutants that are transported at regional and global scales, there is less comfort on the part of many stakeholders in use of trading to address localized pollution. There is also widespread concern within the environmental and environmental justice communities on the use of trading for air toxics. Other key design issues include whether trading replaces or augments existing environmental requirements (the redundancy of requirements can create backstops that prevent adverse local effects), the stringency of the cap, and the allocation of allowances to sources in excess of their actual emissions. Also, there is a concern that allowances be appropriately tracked to prevent fraud and emissions monitored to ensure that the quality of the air is improving (Center for Progressive Regulation, 2004).

4. GROUND LEVEL OZONE

4.1. Introductory Overview

Ground level ozone was listed as one of six criteria pollutants in the Clean Air Act (CAA), which required States to develop state implementation plans (SIPs) for ozone. Despite over 30 years of effort, ozone continues to be a problem in many parts of the US. The strategy for addressing ozone has changed several times following advances in the science related to the importance of controlling precursor pollutants, NO_x and VOC, and the importance of the transboundary nature of emissions. Initially, it was believed that VOC controls alone would bring areas into attainment for ozone, and the focus of ozone mitigation efforts was primarily on reducing VOC emissions throughout the 1970s and most of the 1980s. In the late 1970s, a new scientific study found that ozone formation depends on the ratio between VOC and NO_x emissions and suggested that an appropriate ozone control strategy should reduce both VOC and NO_x emissions. However, a number of model analyses based on the available emissions inventories demonstrated that VOC emissions would be sufficiently effective and therefore ozone regulations remained focused on reducing only VOC emissions. Yet, most areas remained in nonattainment status, and by the mid-1980's, it became clear that few areas would actually meet the 1987 deadline (NRC, 2004).

At the same time, there was growing appreciation for the importance of NO_x emission reductions. California took the first attempt to control NO_x emissions in the mid-1980s, and better understanding of the complex ozone formation system confirmed NO_x control as an essential component for reducing ozone pollution (NRC, 2004). Eventually, the 1990 CAA Amendments (CAAA) contained specific regulations to reduce emissions of NO_x to address ozone formation in nonattainment areas. These requirements were implemented at roughly the same time as national requirements to reduce NO_x emissions to address acidification. Concurrently, transport of NO_x emissions became a greater concern, due in large part to the tall stacks that were installed in the mid-1970s to avoid local health effects. This knowledge was further advanced with modelling conducted in the late 1990s which helped pinpoint the upwind contributions to ozone formation in the Northeast, upper Midwest and even in parts of the South. As a result, the US efforts to control ozone formation contain a mix of air quality limit values, air planning processes, and local, state, regional, and federal control measures.

4.2. Sources of Emissions

A variety of sources release NOx and VOC air emissions that contribute to ozone formation in the US. In Figure 1 we present the contributions from major source categories in 1990, the starting point for recent efforts to address ground level ozone formation.

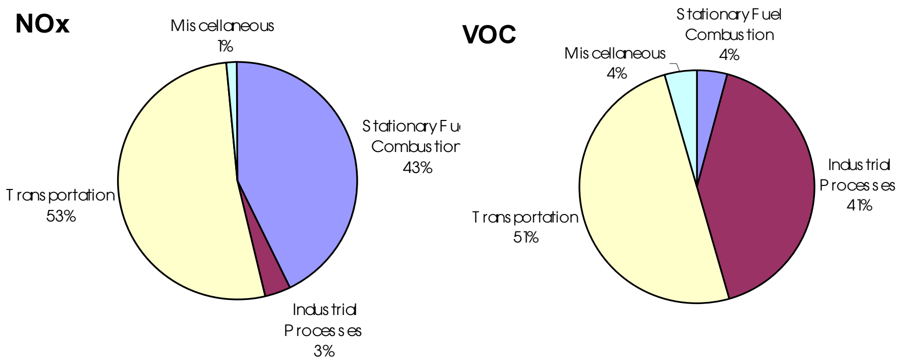


Figure 1. National average NO_x and VOCs emission categories for 1990 (EPA, 2003c)

In 1990, stationary fuel combustion by power generators and industrial sources were significant sources of NO_x emissions. The power sector accounted for 26 percent of NO_x, while fuel combustion at industrial sources accounted for 12 percent. Transportation sources contributed over half of both NO_x (53 percent) and VOC (51 percent) emissions and industrial processes accounted for a large share of the remaining VOC emissions inventory (41 percent).

5. LEGISLATION AND MEASURES IMPLEMENTED

5.1. Air Quality Limit Values: National Ambient Air Quality Standards

In 1979, EPA established the current 1-hour NAAQS for ozone at 0.12 ppm with attainment to be achieved by the end of the decade. This standard was developed to protect both human health—primary standard—and welfare—secondary standard.[35] Ozone concentrations were assumed to be of

---

[35] In 1971, EPA hastily promulgated an ozone standard of 0,08 ppm to meet the requirements of the 1970 CAA. In response to concerns with the vehicle emissions controls being developed to meet the standard, concerns over

concern only at levels above 0.12 ppm, and the average maximum exposure time was assumed to be no longer than one hour. Areas failed to meet this standard if they exceed the standard at any monitoring site in the area more than three times in a three-year period. In 1991, EPA designated 98 areas[36] as being in nonattainment for the one-hour standard, setting in motion a State Implementation Plan (SIP) process geared towards achieving the standards.[37] Current emissions control strategies at the state and regional levels focus on reducing the highest hourly average concentrations. This hourly standard, however, is slowly being phased out as areas meet the attainment standards for three consecutive years, and will be replaced with a new 8-hour standard.

This new 8-hour standard, proposed in 1997 and finalized in 2004, seeks to address adverse impacts associated with longer exposures to lower levels of ozone pollution. The 8-hour standard was devised based on updated scientific knowledge of ozone and the understanding that ozone concentrations may have adverse health impacts at levels at or below the old 1-hour standard, particularly children and adults engaged in outdoor activities. In April 2004, EPA designated and classified nonattainment areas with this new standard, based on a three-year average of the fourth highest 8-hour averaged concentration observed each year. EPA also announced the phase I final implementation rules for the transition from 1-hour to 8-hour standards, and required newly designated nonattainment areas to submit SIPs by 2007.

The replacement of the 1-hour ozone standard with the more stringent 8-hour standard nearly doubled the number of ozone nonattainment areas from 67 to 126 (EPA, 2004a). While the status of nonattainment areas in California and the eastern seaboard from Virginia to Maine did not change significantly, many states in the Southeast, Mid-Atlantic and Midwest gained newly designated nonattainment areas under the 8-hour standard. Changes in the number of nonattainment areas in those states are seen below in Table 1.

Table 1. States with significant increase in the number of ozone nonattainment areas (EPA, 2004a)

Nonattainment Areas	**Standard**	
	1-hr	**8-hr**
AL	0	1
AR	0	1
CO	0	1
GA	1	4
IL	1	2
IN	1	12
KY	0	4
MI	0	12
MO	0	1
NC	0	7
OH	1	11
SC	0	3
TN	0	6
WI	1	5
WV	0	6

States with areas in non-attainment for ozone must meet a specific set of requirements designed to bring the area into attainment. These requirements and the date on which attainment must be met vary depending on the classification, from marginal to extreme. The classifications, design values, and attainment dates for the one-hour and the eight-hour primary standards are shown in Table 2.

---

the science underlying the standard, and evidence that the standard would not be met, EPA reviewed and ultimately replaced this standard (Landy et al., 1994).

[36] EPA later designated 6 additional areas as being in nonattainment status for the 1-hour standard.

[37] For details on the SIP process, see case study #2.

Table 2. Attainment Dates for Nonattainment Areas for Ozone

Criteria Pollutant	Area Classification	Design Value (ppm)	Attainment Date
O_3 (1-hr)	Marginal	0,121 – 0,138	Nov 1993
	Moderate	0,138 – 0,160	Nov 1996
	Serious	0,160 – 0,180	Nov 1999
	Severe-15	0,180 – 0,190	Nov 2005
	Severe-17	0,190 – 0,280	Nov 2007
	Extreme	0,280 ≤	Nov 2010
O_3 (8-hr)	Marginal	0,085 – 0,092	Apr 2007
	Moderate	0,092 – 0,107	Apr 2010
	Serious	0,107 – 0,120	Apr 2013
	Severe-15	0,120 – 0,127	Apr 2019
	Severe-17	0,127 – 0,187	Apr 2021
	Extreme	0,187 ≤	Apr 2024

Combinations of measures work in tandem to help achieve the NAAQS, including measures at the national, regional, state, and local levels, as described below.

5.2. National Control Measures

Several measures related to transportation and stationary sources have been developed and are being developed at the federal level to assist states in achieving attainment with the ozone standard. Table 3 lists the major national NO_x and VOC emission control programs.

Table 3. National NO_x and VOC Emission Control Programs (EPA, 2004c)

Sector		Program	NO_x Reductions	VOC Reductions
Transportation	LD Vehicles & Trucks	Tier 1 Emission Standards	X	X
		National Low Emission Vehicle Program	X	X
		Inspection and Maintenance	X	X
		Reformulated Gasoline	X	X
		Evaporative Controls		X
		Reid Vapour Pressure Controls		X
Stationary	Electric Utilities	Acid Rain Program	X	
		Ozone Transport Commission NO_x Programme*	X	
		NO_x State Implementation Plan Call	X	
	Chemical Manufacturing	Synthetic Organic Chemical Manufacturing Maximum Achievable Control Technology		X
	Other Stationary Source	Clean Air Act Solvent and Coating Controls		X

*Currently, there are additional programs proposed in the OTC NO_x Program.

5.2.1. Transportation Measures

The 1990 CAA Amendments tightened NO_x and VOC emissions from mobile sources with a variety of control programs such as emissions standards for new vehicles and engines, vehicle inspection and maintenance (see case study 3 for more details), retrofits to existing vehicles, and specifications on fuel properties and vapour controls. These national control measures and their anticipated emission reductions play a major role in SIP implementation (NRC, 2004).

5.2.1.1. Vehicle Engine Emissions Standards

The CAA authorizes EPA to establish emissions standards for light-duty vehicles and light-duty trucks ("passenger vehicles"), heavy-duty vehicles, and non-road vehicles and engines. Each vehicle type has gone through a different set of engine emission standards, timing, and implementation requirements.

The CAAA of 1990 further tightened emission standards for light-duty vehicles. The new limits, the "Tier 1" passenger vehicle standard, became effective beginning in 1994 and was fully implemented in 1997. In 1997, EPA finalized the regulations for the National Low Emission Vehicle (NLEV) program, which provides more stringent emission standards for the transitional period before the Tier II standards are introduced. This voluntary program came into effect through an agreement between the Northeastern states and auto manufacturers.[38] In 1999, national standards were further tightened to the "Tier II" standards, to be phased-in beginning in 2004. In addition to the engine emissions standards, Tier II also includes new fuel quality standards.[39]

EPA has also promulgated a set of continuously tightened emissions standards for heavy-duty vehicles and buses. Model year 1988-2003 heavy-duty highway vehicles are required to meet a set of standards that vary based upon the age and type of vehicle. These standards were further tightened in 1997 to apply to model year 2004 and later vehicles. The goal was to reduce NO_x emissions from highway heavy-duty engines to levels approximately 2,0 g/bhphr beginning in 2004. In 2000, EPA further tightened the standards for model year 2007 and later heavy-duty highway engines to 0,20 g/bhp-hr.[40]

EPA has also established engine emissions standards for non-road vehicles, locomotives, and marine engines. In 1994, EPA adopted the first federal standards, "Tier I" nonroad diesel engines, which was to be phased-in from 1996 to 2000. These were further tightened in 1998 under the "Tier 2 and 3" non-road vehicle standard. More recently, in May 2004, EPA finalized the "Tier 4" standards that are to be phased in between 2008 and 2015.[41]

5.2.2. Reformulated Gasoline and Vapour Recovery

Legislative and regulatory requirements have been issued to reduce emissions specifically from combustion and evaporation of gasoline. The CAA and subsequent EPA regulations have developed requirements for use of gasoline that is designed to burn cleaner—reformulated gasoline (RFG). The CAA requires the use of RFG in cities with the worst ozone pollution, but other cities may choose to use RFG.[42] The CAA also specified that RFG contain 2 percent oxygen by weight by using additives such as MTBE (methyl tertiary butyl ether) and/or ethanol. Oil companies can decide which substance to use.

In addition, beginning in 1989, EPA required gasoline to meet volatility standards (in two phases) to decrease evaporative emissions of gasoline in the summer months. The Onboard Refuelling Vapour Recovery (ORVR) program required vehicle manufacturers to install equipment to capture refuelling emissions in passenger cars and light trucks (e.g. pickups, mini-vans, and delivery and utility vehicles). The standards were phased in over three-year periods, beginning in 1998 for new passenger cars, 2001 for light trucks under 2722 kg (GVWR), and 2004 for light trucks from 2722-3856 kg. Heavy-duty vehicles and trucks over 3856 kg were not affected by the standard. The rule thus covered 97 percent of new vehicles and 94 percent of refuelling emissions. The refuelling standard was set at 0,20 grams per gallon of dispensed fuel, leading to a 95 percent reduction in emissions relative to the uncontrolled levels (the control level mandated by the Clean Air Act Amendments). When fully phased in, the rule was projected to reduce VOCs and toxins by 0.3 to 0.4 million tonnes per year nationwide, a one-to-

---

[38] While "voluntary" this program is enforceable in the same manner as any other federal new motor vehicle program.
[39] For more details on the specifics of the standards, see: www.dieselnet.com/standards/us/light.html
[40] For more details on these standards, see: www.dieselnet.com/standards/us/hd.html
[41] For more details on these standards, see: www.dieselnet.com/standards/us/offroad.html
[42] For more information, see EPA (2004b).

two percent reduction in national VOC emissions. EPA also estimated an annual savings in gasoline of about 303 million litres per year in the 1998-2000 period. The net cost (ORVR system minus fuel savings) of the program was estimated at about $5 per vehicle.

5.2.3. Stationary Source Controls

The U.S. CAA also requires national measures on stationary sources to reduce ozone precursors through the Acid Rain program, Reasonably Available Control Technology (RACT), New Source Performance Standards (NSPS), and New Source Review (NSR).

5.2.3.1. Reasonable Available Control Technology

Title I of the 1990 Clean Air Act Amendments required emission rate limits consistent with reasonable available control technology (RACT) for large point sources of both VOCs and NO_x in nonattainment areas and in both attainment and nonattainment areas within the ozone transport region. The goal of RACT was to reduce emissions to 15 percent below 1990 levels by 1996. Regions still not meeting attainment must meet an average 3 percent annual reduction in NO_x emissions, VOC emissions or combinations of the two over every three continuous years until the NAAQS is achieved. States had some flexibility in how RACT was defined. For example, New England states defined RACT as category-wide emissions rate limitations of control technology requirements, whereas Pennsylvania defined RACT as the implementation of low-NO_x burners (Burtraw and Evans, 2003).

5.2.3.2. New Source Performance Standards

New sources of power generation with capacities greater than 25 MW must meet a new source performance standard of 0,73 kg of NO_x per MWh. This same standard applies to all fuel types. This effectively requires some post-combustion control such as selective catalytic reduction (SCR) at new steam boilers. Existing power generators that become subject to NSPS through modification must meet a standard of 0,07 kg/kJ. Industrial sources must meet a standard of 0,05 to 0,09 kg/kJ, depending on the fuels used and other factors.

5.2.3.3. New Source Review

The 1977 Clean Air Act Amendments established two New Source Review (NSR) programs applicable to construction of new sources and to modifications at existing sources that might increase emissions of NO_x or other pollutants. New source review requirements apply to power generating facilities as well as to other industrial sources. New or modified sources locating in clean air areas (attainment areas) are subject to the prevention of significant deterioration (PSD) program, while sources locating in nonattainment areas are subject to a nonattainment NSR program. Sources that trigger new source review for a given pollutant must install Best Available Control Technology (BACT)[43] or Lowest Achievable Emissions Rates (LAER)[44] technology for that pollutant, depending on whether they are subject to PSD or nonattainment NSR, respectively. Sources triggering nonattainment NSR must also acquire emissions offsets.

Implementation of the NSR program has shifted over time, with changing regulations and guidance on how modified sources are defined and how NSR is triggered as well as different emphasis on compliance and enforcement. One important interpretation of the NSR provisions was the 1992 "WEPCO" rule, a regulation addressing how to calculate the increase in emissions resulting from major modifications to electric utility steam generating units. This rule had the effect of allowing emissions increases associated with load growth to be deducted from the calculation on how NSR is triggered. However, there was still uncertainty within the industry community about the kind of modifications that would trigger NSR. Some companies opted to postpone modifications to their facilities while

---

[43] BACT is set on a case-by-case basis, and must be at least as stringent as the NSPS. In practice, BACT has often been set to be equivalent to reduction levels that can be achieved with low-NOx burner technology.

[44] LAER requirements are set on a case-by-case basis, considering the lowest achievable emission rates and cost considerations. Massachusetts and California designated SCONOX as LAER, and have set LAER at approximately 2-3 ppm, which translates roughly to 0,01 kg/kJ.

others made modifications they deemed to be "routine maintenance" and therefore not subject to the requirements. In 1996, EPA proposed to make changes to the existing NSR program that would significantly streamline and simplify the program. In the late 1990s, EPA pursued a number of enforcement actions against companies suspected to be in violation of NSR. In 2000, EPA issued a final rule specifying a more lenient interpretation of actions that would trigger NSR. This rule continues to be the subject of political and legal controversy.

5.2.3.4. VOC Controls

The 1990 CAAA required study of VOC emissions from consumer and commercial products resulted in establishment of national emission standards for architectural coatings, consumer products and automobile refinish coatings to reduce VOC emissions. In addition, EPA established maximum achievable control technology (MACT) standards for several solvent subsectors, often referred as national emissions standards for hazardous air pollutants (NESHAPs) in 2002. Implementation of control measures for NESHAPs is expected to reduce significant amounts of VOC emissions.

5.3. Regional Measures Addressing Ozone Transport

As science has progressed, there has been progressively greater recognition of the regional contribution to local ozone nonattainment. The 1990 CAAA and recent implementation of the CAA contain several provisions that seek to reduce the regional contribution of emissions.

5.3.1. Ozone Transport Commission

Section 176 permits the creation of transport commissions to deal with regional transport, and section 184 specifically created the first such commission, the Ozone Transport Commission (OTC), to coordinate actions among the thirteen Northeastern and Mid-Atlantic states and the District of Columbia to end the persistent non-attainment along the Northeastern Corridor. In 1994, these jurisdictions signed a Memorandum of Understanding that established a three-phase "NO_x Budget Program" to control NO_x emissions from electric utility and large industrial boilers. Phase I was equivalent to the RACT standard in 1995. Phases 2 and 3, starting in 1999 and 2003, consist of a progressively more stringent cap-and-trade program for the entire region during the May to September ozone season. The states together developed a model emissions trading rule that all could adopt. Each state retained control over how to allocate emissions within their state.

While similar to the acid rain trading system described earlier, a key difference entailed limits placed on banked allowances through a system involving progressive flow control. Progressive flow control limits the number of banked allowances that can be used during a compliance period to prevent significant increases in emissions over the emissions cap. Most of the time banked allowances are credited on a one-for-one basis (i.e., one banked allowance must be retired to cover one ton of NO_x emissions), but when flow control comes into effect, banked allowances are credited on a two-for-one basis (i.e., two banked allowances must be retired to cover one ton of emissions). The point at which flow control comes into effect is determined annually using the following equation:

$$\frac{\text{10\% of Total Budget}}{\text{Total Banked Allowances}} = \text{Flow Control (\%)}$$

In this equation, "Total Budget" refers to the total number of allowances in the program for a particular year. "Total Banked Allowances" refers to the total number of banked allowances held by installations in the program. "Flow Control" is a percentage that establishes the point at which flow control comes into effect (see Box 1 for example).

Box 1: A Hypothetical Example of the Flow Control in the OTC NOx Budget Program

For example, assume there are 100 allowances in the program for a given year and the total number of banked allowances is thirty, such that the numerator of the flow control equation is ten (10% x 100 = 10) and the denominator is thirty. The point at which flow control comes into effect is at 33 percent of total banked allowances (10 ÷ 30 = 33%). Although this flow control threshold is calculated on a macro level across the whole program, it is applied on a micro level. For example, if a particular installation has nine banked allowances and is subject to the 33 percent flow control, it can use its first three banked allowances on a one-for-one basis (33% x 9 = 3) and the remaining six on a two-for-one basis. In total, flow control will only allow this installation to receive five tons of credit for its nine banked allowances

The OTC NO_x budget program got off to a somewhat rocky start due to a hurried and awkward phase (Farrell, 2000). There were delays in the laws needed to implement the program, and delays in issuance of early reduction credits, creating uncertainty in the market. In fact, "although a few emissions trades were announced as early as January 1998, the (trading) system was not on line until September 1998 and trading did not begin in earnest until the beginning of 1999"—just before the first May to September compliance period (Farrell, 2000). These uncertainties lead to high degrees of price volatility in the first year of the program. At the same time, the market provided the signals needed to correct the short supply of allowances as well as tools to manage future risks, and prices levelled out in the next year without adverse impacts on reliability or emissions (Farrell, 2000).

5.3.2. OTAG

In the mid-1990s, Eastern states expressed concerns about the impact of Midwestern states' emissions on their air quality and their limited ability to achieve attainment of NAAQS through cost-effective in-state actions. These eastern states had already undertaken significant local actions to reduce NO_x and VOCs and saw little progress towards attainment as the air coming into their states in many cases already exceeded attainment levels, or nearly so. The Midwestern states in question were generally not covered by nonattainment requirements, since these areas met the NAAQS, and therefore did not need to reduce emissions to improve their air quality.

EPA partnered with all 37 of the states east of the Mississippi River in 1995 to form the Ozone Transport Assessment Group (OTAG). OTAG's mission was to identify approaches to limit the transport of ozone precursors between the Midwest and South regions on the one hand and the Northeast region on the other. A significant amount of analysis was conducted to understand the contributions of the various OTAG states to nonattainment. A key finding was that for some states such as Wisconsin and Maryland, NO_x concentrations in ambient air entering the state already exceeded the NAAQs. The result of the OTAG process was a consensus recommendation to EPA for a new regulatory initiative to reduce NO_x emissions throughout the region. The recommended reduction level was expressed as a range, from something approaching business as usual to an 85 percent reduction.

In response, EPA developed an emissions trading system known as the "NO_x SIP Call." Under the NO_x SIP Call, EPA established NO_x emissions caps for 22 member states and the District of Columbia based on each state's contribution to the problem rather than its attainment status with its SIP. States deemed to contribute to ozone nonattainment were given NO_x emission budgets equivalent to an emissions rate of 0,07 kg/kJ[45], while those deemed not to contribute were excluded from the program. States may choose to participate in an interstate trading program to reach compliance with the NO_x SIP Call by accepting the major elements of a trading program defined in EPA's model rule. This program will subsume the OTC trading program.

---

[45] EPA's methodology for assigning state allocations was upheld by the courts, in Michigan v. EPA.

While the program was originally supposed to be effective on May 1, 2003, controversy surrounding this method for capping NO_x emissions led to legal challenges from affected states and industries questioning EPA's legal authority and basis for setting the cap level. The program launch has been delayed by these legal challenges, but the cases are now settled and the program is slated to begin on May 31, 2004—nine years after OTAG's inception—and will be applicable to a more limited number (19) of states and the District of Columbia.

5.3.3. 126 petitions

Section 126 is a legal mechanism under the Clean Air Act authorizing states to petition EPA to address emissions from sources in upwind states that significantly contribute to nonattainment. If EPA finds that the sources make a significant contribution to nonattainment problems in the petitioning state, EPA is then authorized to establish federal emission limits for the offending sources. A number of states have used this authority to encourage regional reductions in NO_x emissions contributing to ozone nonattainment. For example, in 1997, eight Northeastern states filed 126 petitions against power generators and other sources of NO_x in the Midwest, South and Northeast. An additional 3 states filed petitions in 1999. These petitions were considered within and alongside the OTAG process, described above, and helped result in EPA's final NO_x SIP Call determination. These have continued to be used, such as a recent North Carolina section 126 petition, and could potentially play a significant role in future air quality efforts.

5.3.4. Clean Air Interstate Rule

A rule recently proposed by EPA, the Clean Air Interstate Rule (e.g., "Transport Rule"), seeks to reduce interstate transport of fine particulate and ozone pollution to help states meet the new 8-hour ozone and fine particle national ambient air quality standards. This rule would establish emissions caps in two phases (2010 and 2015) for NO_x and SO_2 in 28 states and the District of Columbia.[46] Note that the states participating in the proposed Clean Air Interstate Rule are a subset of states subject to the current Acid Rain Trading Program, which covers 48 states. However, the Transport Rule proposes to include more states than currently participate in the NO_x SIP Call. As a result, the cap levels are not directly comparable. Also, the NO_x cap under the rule would be annual, as opposed to the earlier seasonal ozone cap. Overall, this rule would reduce NO_x emissions in the region to 1,4 million tonnes in 2010 and 1,2 million tonnes in 2015, approximately 65 percent below current levels. The program would also simultaneously reduce SO_2 emissions in the region. SO_2 emissions would be reduced by 3,3 million tonnes in 2010—approximately 40 percent below current levels—and an additional 1,8 million tonnes when the rule is fully implemented—approximately 70 percent below current levels.[47] The control levels were established based on what was deemed to be highly cost-effective. According to the proposed rule, the SO_2 emissions limits correspond to 65 percent of the affected states' Title IV allowances in 2015 (and 50 percent of the affected states' Title IV allowances in 2010). Similarly, the NO_x emission limits correspond to the sum of the affected states' historic heat input, multiplied by an emissions rate of 0,132 kJ in 2015 (and 0,16 kJ in 2010).

5.4. State and Local Actions

Under the CAAA, states are responsible for meeting the NAAQS by, as needed implementing various nationally-defined requirements at the state and local levels and by future controls on in-state sources. Ozone non-attainment areas must all meet a series of specific, statutory provisions, including development of a vehicle emission-control inspection and maintenance program (see case study 3), and an offset program with a 1,1:1 retirement ratio for new VOC sources. Depending on the area classification, a number of additional measures may also be required (see Table 5 below).

---

[46] The state of Connecticut was found to contribute to downwind ozone pollution but not to fine particle pollution, and therefore is only required to limit seasonal NOx emissions. If Connecticut opts into the annual trading program, there would be 29 states in total, and the cap levels described above would be adjusted to reflect Connecticut's capped emissions.

[47] More information on the rule is available at: www.epa.gov/air/interstateairquality/

Table 5. Selected Requirements for Ozone Nonattainment Areas, by Category (NRC, 2004)

Marginal and above	Include an emission control vehicle inspection and maintenance program Include a VOC and NOx emissions inventory every three years Implement new source review for VOC sources that includes an offset ratio of emissions reductions to new emissions of at least 1,1:1
Moderate and above	Provide a plan for VOC emissions reductions as specified in the CAA Provide a plan for comprehensive introduction of Reasonably Available Control Technology (RACT) for specified VOC sources Implement a vapour recovery program requiring gasoline service stations to install special refuelling equipment to prevent the escape of VOCs Implement a new source review for VOC sources that includes an offset ratio of emissions reductions to new emissions of at least 1,15:1
Serious and above	Include an attainment demonstration using a photochemical grid model Demonstrate that reasonable progress is being made through appropriate 3 percent per year reductions in VOC emissions (or its ozone-equivalent NOx emissions) and submit triannual compliance demonstrations beginning in 1996 showing emission reductions are being met Implement a new source review for VOC sources that includes an offset ratio of emission reductions to new emissions of at least 1,2:1 Implement a program of enhanced air quality monitoring Provide for an enhanced vehicle I/M program Include a clean fuel vehicle program for centrally fuelled fleets Demonstrate conformity with regional transportation plans
Severe	Implement transportation control measures to reduce single-occupancy vehicle use through high occupancy vehicle (HOV) lanes and car-pooling and van-pooling programs Implement a new source review for VOC sources that includes an offset ratio of emission reductions to new emissions of at least 1,3:1 [or 1,2:1 if area-wide best available control technology (BACT) is used]
Extreme	Include a plan for use of clean fuels and advanced technology for electric utility, industrial and commercial boilers Implement a new source review for VOC sources that includes an offset ratio of emission reductions to new emissions of at least 1,5:1 (or 1,2:1 if area-wide BACT is used) Implement a reformulated fuels program

Beyond the federally-mandated provisions outlined above, states and localities have implemented additional measures to achieve attainment. Some non-attainment areas rely predominantly on state and local actions whereas others rely almost entirely on reductions from national and regional actions.

While a number of different approaches have been used to achieve reductions in local emissions contributing to ozone nonattainment, we focus here on the use of trading mechanisms to reduce NO_x and VOC emissions. Following EPA's development of draft guidelines for states to use economic incentive programs in their state implementation plans, several states have implemented various types of trading programs. Two main designs have been used: cap-and-trade (California, Illinois) and "open-market trading" (Michigan, Texas, New Jersey, Pennsylvania, Colorado and Washington).

5.4.1. California South Coast RECLAIM Program

The California South Coast Air Quality Management District (SCAQMD) established the Regional Clean Air Incentives Market (RECLAIM) NO_x[48] emissions trading program to help bring Orange County and the urban portions of Los Angeles, Riverside and San Bernadino counties, an extreme nonattainment area for ozone, into attainment by November 2010. Over 350 affected electric power plants and industrial sources were assigned a quantity of RECLAIM Trading Credits (RTCs) based on past peak production levels and the requirements of existing rules and control measures. The overall goal of RECLAIM was to reduce NO_x emission by 73 tonnes per day, an overall reduction of 70

---

[48] The RECLAIM program also addressed SOx emissions.

percent from affected sources, by 2003. To ensure that the desired reductions levels are achieved in the compliance year, emissions banking was not permitted. In 1994, the first year of the program, RTCs (the emissions cap) totalled 36.403 tonnes. The cap decreased annually to 14.236 tonnes in 2001. Note, however, that participating sources represent only about a quarter of the area's ozone-forming air pollution. The majority of NO_x emissions in the SCAQMD region come from the transportation sector, which was ultimately not included in the RECLAIM program.[49]

5.4.2. Illinois VOC Trading Program

In 2000, the Illinois EPA launched a cap-and-trade program, the Emissions Reduction Market System (ERMS), to reduce VOC emissions in Chicago, a severe ozone non-attainment area. The cap was set to reduce stationary-source VOC emissions by 12 percent from a historical benchmark.[50] All sources with baseline or actual emissions over nine tonnes during the ozone season were required to participate, and allowances were allocated for free to maintain industry competitiveness. While trading of emissions was unrestricted, banked allowances expire after one year. This program did not require use of continuous emissions monitors.

The Illinois ERMS program began a year later than initially proposed due to participant concerns about their ability to comply under a trading system. Once the program began, compliance was not an issue. However, there are indications that the market is not working as well as it could. Limited numbers of total trades, declines in the number of trades and allowance prices over the two years of the program, and the expiration of banked allowances in the second year of the program suggest that companies are not optimally using the market to minimize compliance costs. In addition, market participants and observers had difficulty obtaining accurate and timely information on the price of allowances (Kosobud et al, 2004).

5.4.3. Open Market Trading Programs

A handful of open-market trading (OMT) programs were established in the late 1990s to add compliance flexibility and lower the cost of reducing NO_x and VOC emissions by extending the universe of emission reduction sources. Unlike cap-and-trade programs, open-market trading programs do not cap emissions at a particular level. Rather, they establish rules for uncapped sources to generate credits on a project basis that can be used, banked or traded to comply with existing requirements such as RACT. Specific rules differ across the various state programs, including what counts as a reduction and restrictions on trades.

EPA (2002c) provided non-binding guidelines for states to follow in developing OMT systems and suggested that programs adhere to three general principals:

- Traded emissions should be surplus to what is required by existing regulations.
- Changes in emissions levels should not be inequitably distributed across population groups.
- Systems should ensure environmental improvements.

EPA also encouraged data tracking procedures that would chronicle the generation and use of credits, approved quantification protocols for all trades, and disallowed credits for facilities that cease operations.

Open-market trading has some design flaws that raise criticisms from economists and environmental groups. Economists criticise the lack of well-defined markets and the effect that low-cost discrete emissions reductions have on the incentives for regulated sources to create new emissions reductions. Environmentalists contend that many of the discrete emissions reductions would have occurred anyway

---

[49] Note that the original design of the RECLAIM program permitted trading between stationary and mobile sources, in the end, EPA approved only a limited trading program. Allowing participants to invest in and trade with mobile sources would have added compliance flexibility.

[50] Note that additional measures were established in Illinois to reduce mobile and area source emissions of VOCs.

and therefore should not warrant credit (NRC, 2004). Allowing "anyway tons" to be used for compliance reduces the overall effectiveness of the existing regulations that the open-market trading flexibility mechanism was developed to serve. In addition, a number of the programs that have been implemented have suffered from a variety of flaws in implementation (see box below).

Box 2: Open Market Trading Systems in Practice

In practice, many of the OMT program designs differ from the EPA guidance. This was largely because the OMT programs became operational in the mid 1990s while the EPA guidance was not complete until January 2001. For example, the Michigan program allows for lead to be traded and EPA does not support this. In addition, "shutdown" credits are available in Michigan to companies that cease operations – also contrary to EPA guidance.

The New Jersey Open Market Emissions Trading (OMET) program ran into a number of problems in implementation that ultimately caused the New Jersey Department of Environmental Protection (DEP) to terminate the program in 2004. The main problem stemmed from questionable verification of DER credits by the private company contracted to provide this service. For example, credits generated may have been overstated, and in at least one case, the registry accepted a non-ozone season DER for compliance during the ozone season. In addition, the DEP cites acceptance of credits generated many years before the credits were used, and facilities relying on purchase of emissions credits for their compliance strategies. (NJ DEP, New Jersey Register, August 4, 2003).

6. ASSESSMENT OF THE EFFECTIVENESS.

Below we discuss the effectiveness of US efforts to control ozone formation by considering the environmental effectiveness, costs, compliance and enforcement, administrative feasibility, and political acceptability.

6.1. Environmental Effectiveness

Two factors are evaluated in assessing the environmental effectiveness: emissions reductions achieved and concurrent impacts on air quality.

6.1.1. Emissions

The various stationary and mobile source programs implemented since 1970 have contributed to reductions in national NO_x and VOC emissions, as shown in Figure 1. Most of the NO_x emission reductions have occurred since 1990, during which time NO_x emissions have decreased by 22 percent, approximately 5.0 million tonnes (EPA, 2004c). Most of this decrease came from on-road motor vehicles and electric utilities, which have reduced emissions by 2.3 million tonnes (a 26 percent reduction) and 2.2 million tonnes (36 percent reduction), respectively. More recently, the rate of reduction has increased significantly as new laws and regulations have been adopted and new technologies have been introduced. VOC emissions have declined steadily over the last 30 years, dropping approximately 48 percent since 1980 and 32 percent since 1990 (EPA, 2004c). Since 1990, most of this decrease came from on-road motor vehicles and solvent utilization, which has reduced VOC emissions by over 5 million tonnes (55 percent reduction) and 1 million tonnes (20 percent reduction), respectively.

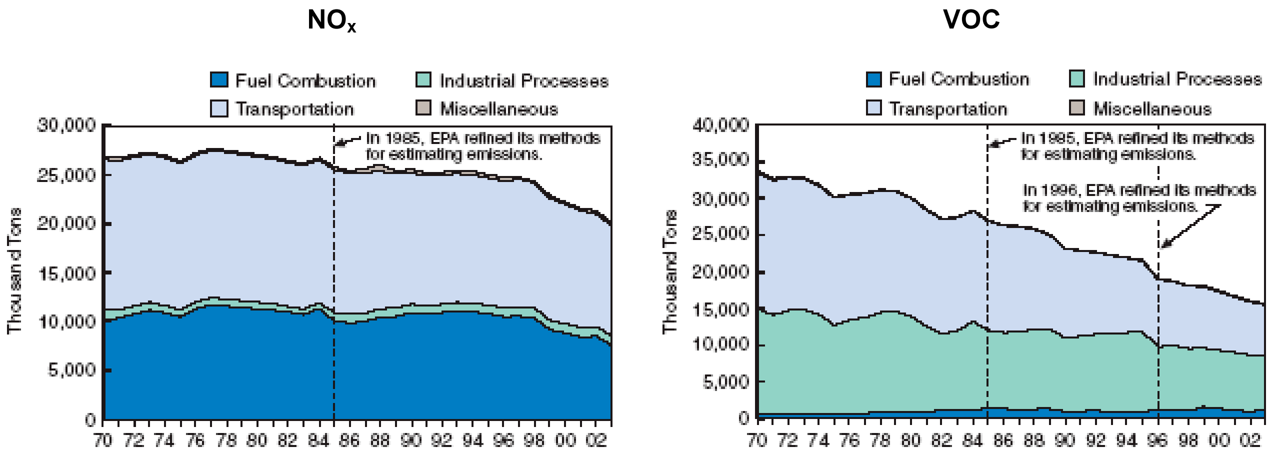


Figure 1. U.S. National Trends in NO_x and VOC emissions, 1970-2003.

Several recent promulgated regulations—Large Spark-Ignition, Tier II, Heavy Duty Diesel, and Nonroad Diesel—or proposed rules—such as the Interstate Air Quality Rule—are expected to further reduce US NO_x emissions in the coming years (see Figure 2). More details on the Tier II, Heavy Duty Diesel, and Nonroad Diesel rules are provided in case study 4.

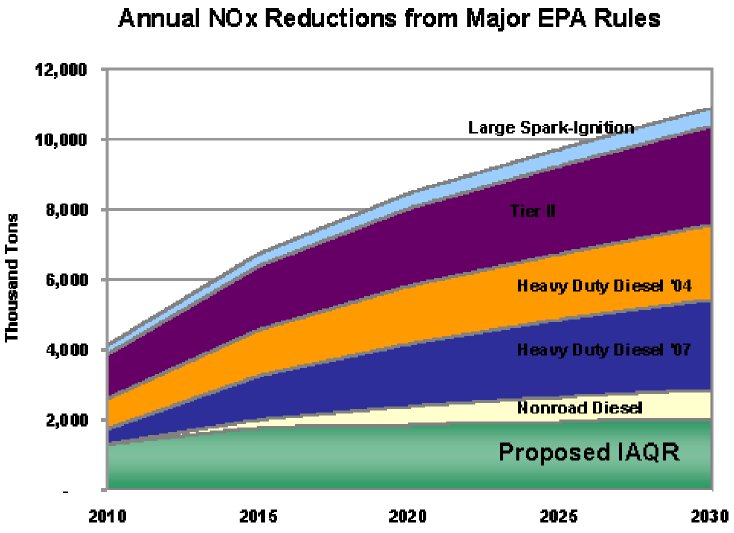


Figure 2. Annual NO_x emissions reductions from major EPA rules (EPA, 2004h)

While it is impossible to completely separate out the impacts of a single program, since the programs often overlap and have a variety of impacts, several assessments have sought to discern the impacts of a limited number of the specific efforts to control ozone formation.

6.1.1.1. OTC NO_x Budget Program and the NO_x SIP Call

As expected, with implementation of the OTC requirements, NO_x emissions reductions have been considerably greater in the Northeast than in other parts of the country. Emissions sources in the Ozone Transport Region NO_x Budget Program reduced regional summertime ozone emissions from roughly 429.098 tonnes in 1990 to 290.000 tons in 1995 (the year that RACT requirements kicked in) to 193.000 tons in 2002, the final year of the Phase II NO_x budget period. These 2002 emission levels are about 12 percent below the Phase II budget level of 263.084 tonnes. Overall, through a combination of emissions standards and cap-and-trade approaches, the Northeast region achieved a 59 percent reduction in NO_x emissions between 1990 and 2002. These emissions reductions are roughly comparable in all parts of the Region on a percentage basis. In fact, all states except for Maryland and the District of Columbia had emissions below their NO_x budget levels in 2002, and both average and peak daily emissions have declined in OTC states. Moreover, emissions do not appear to have shifted to upwind states.

A portion (roughly 27 percent) of the allowances banked in the Ozone Transport Region resulted from over compliance during the Phase II budget period will be allowed to be used to help meet the tougher ozone season emissions levels (127.913 tonnes in the Ozone Transport Region starting in May 2003) that were established by the NO_x SIP Call trading program. The rest of the allowances will effectively be retired, representing permanent emissions reductions. These excess allowances are due in large part to the flow control provisions that were established to prevent high (>10 percent) exceedances of the seasonal NO_x budget (OTC, 2003).

Starting in May 2004, the remaining states in the eastern U.S. were required to comply with the NO_x SIP Call, and many sources in these states installed new control technology. In fact, new end-of-pipe controls at some plants subject to the NO_x SIP Call were operational in 2003 or earlier. While emissions results from the 2003 ozone season have not been reported, one group estimated emissions reductions based on publicized plans to install SCR control technology. They estimate that this technology will achieve 75 to 90 percent of the reductions needed from SCR retrofits, and 40 to 50 percent of the gap between BAU NO_x emissions and the SIP Call targets (NESCAUM, 2001).

While significant emissions reductions have been achieved in the Northeast as a result of RACT and the regional control program for point sources, transported emissions from up-wind states and emissions from some mobile sources (e.g. off-road vehicles and engines) have continued to increase. Additionally, growth in vehicle miles travelled, personal automobile usage, and popularity of fuel-inefficient vehicles (e.g. SUVs) offset a significant portion of the emission reductions achieved through transportation-related emission control programs (NRC, 2004). The net result is a more modest 10 percent decrease in NO_x emissions between 1990 and 1999 in the OTC region.

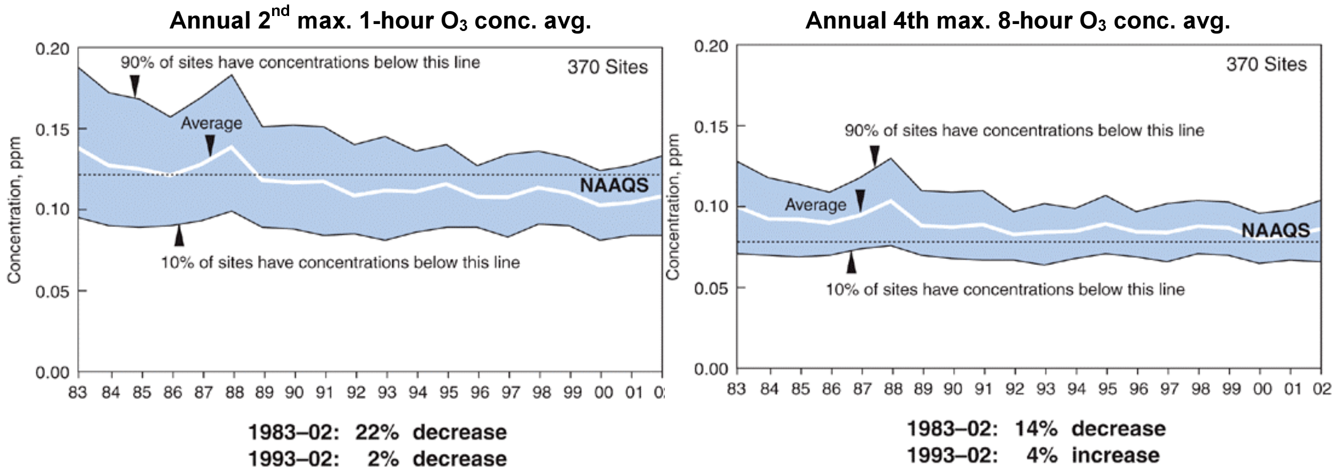
6.1.1.2. The South Coast RECLAIM and programs Illinois VOC Trading

The Illinois ERMS cap-and-trade program noted significant emissions reductions, well in excess of what was required under the program. VOC emissions in Chicago were reduced by 56 and 50 percent from the baseline period in 2000 and 2001 (well in excess of the 12 percent reduction target) without creation of emissions hotspots. However, some of these emissions reductions were likely due to underlying RACT requirements affecting participating sources rather than compliance with emissions caps established by the Illinois EPA. Benchmark emissions during the period 1994 to 1996 were close to 100.000 ATU units, and emissions began to decline shortly after the benchmark period to 51.000 ATU in 1998 and 47.000 ATU in 1999 due to changes in prescriptive regulation. According to Kosobud and his colleagues (2004), this suggests that, “due to prior prescriptive regulation, emissions were forced far below allotments by the time the market went into operation and therefore allotting participants far more ATUs in the aggregate than they needed.” Excess emissions reductions were banked for future use, however, the one-year expiration of these allowances resulted in nearly 15 percent of vintage 2000 allowances going unused, locking in emissions reductions beyond the target (Kosobud et al., 2004). Total “locked-in” reductions for year 2000 come to a 23 percent reduction below the baseline.

From 1994 through 1999, total NO_x emissions from RECLAIM facilities were below the total NO_x allocations, in most years by 25 percent or more. During this period, demand for allowances was relatively low and allowance prices did not encourage substantial investments in control technologies. In 2000, however, due to the California energy crisis, electricity generation at other power production facilities increased significantly, raising the total emissions level and the demand for allowances. As a result, in 2000, total NO_x emissions (18.589 tonnes) exceeded the total allocation by 2.988 tonnes (nearly 20 percent). Emissions dropped significantly in 2001, so that total emissions were only slightly (less than one percent) above the total allocations (SCAQMD, 2003).

6.1.2. Impact

The national trend in O_3 concentrations have declined considerably at monitoring sites across the country over the past 20 years, as shown in Figure 3. From 1983 to 2002, the national 1-hour and 8-hour O_3 levels decreased 22 and 14 percent, respectively (EPA, 2003). However, over the last 10 years, despite implementation of RACT and various efforts to control emissions from mobile and stationary sources, progress in reducing O_3 concentrations has slowed down: from 1993 to 2002, 1-hour O_3 concentrations declined, while 8-hour O_3 concentrations actually increased by 4 percent. Standard statistical tests show that these 10-year trends are not significant and therefore ozone concentrations did not change overall (EPA, 2003).


Annual 2nd max. 1-hour O_3 conc. avg.
Annual 4th max. 8-hour O_3 conc. avg.

1983–02: 22% decrease
1993–02: 2% decrease
1983–02: 14% decrease
1993–02: 4% increase

Figure 3. Trend in 1-hour and 8-hour Ozone Air Quality, 1983-2002 (EPA, 2003)

Nonetheless, these national trends disguise substantial improvements made since 1990 in different parts of the country. Specifically, significant improvements in ozone were reported in the Northeast and West Coast: ozone concentrations decreased in EPA Regions 1, 9, and 10 by 13, 16, and 10 percent, respectively, as shown in Figure 4. Areas in the middle portion of the country (Regions 7 and 8) showed the least improvement during the same period.

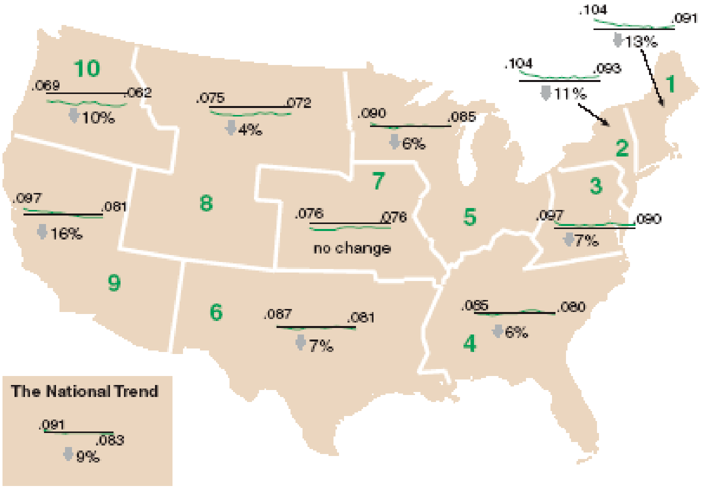


Figure 4. Trend in Fourth Highest Daily Maximum 8-hour Ozone Concentration (ppm) by EPA Region, 1990–2003 (EPA, 2004c)

These very modest regional improvements in ozone concentrations resulted in attainment of the one-hour standard in many parts of the country: the number of nonattainment areas decreased from 132 to 73 from 1992 to 2003 (EPA, 2003a). However, this result may be somewhat misleading as most of the areas reclassified to attainment occurred in the least severe (e.g., moderate, marginal, transitional) attainment categories. The number of areas classified as severe or above have remained unchanged or increased (NRC, 2004). However, programs that have yet to be fully implemented or only in the proposal stage are estimated to further contribute to reductions in ozone formation in the coming years. According to EPA, 26 counties are likely to exceed the 8-hour ozone standard in the East Coast after implementation of the Interstate Air Quality Rule and other measures in 2015 (EPA, 2004h). There is an inherent difficulty in measuring the progress of the programs in terms of ozone formation and health impacts (see box 3).

6.2. Costs

No estimates appear available on the overall costs of US efforts to address ozone formation. However, several assessments have been conducted on the costs of a limited number of the specific efforts to control ozone formation. Below we present results on some of these programs.

6.2.1. Cost-effectiveness

Ex-post cost-effectiveness evaluations have been conducted for a limited number of programs to control ozone formation. Many different firms and types of firms participated actively in OTC market. Power generators were the most active, accounting for 91 percent of the initial allocation and 98 percent of trades. However, allowance brokers, cogenerators, refineries and manufacturing firms also participated. The market developed quickly, including development of an options market to hedge risks. A total of 15 percent of allowances (32.000 allowances) changed hands in 1999 between distinct entities and more (42.000) moved within firms. Presumably low cost compliance opportunities were identified and resulted in these trades. The market helped facilitate compliance, but costs in first year were higher than projected and more volatile due to uncertainties described earlier. One way to calculate cost-effectiveness is to consider the market price in an emissions trading system. Initial forecasts of the cost of an allowance in the OTC program were estimated at $551-2.755 per tonne, while the actual cost ranged between under $1.102 to nearly $7.203 per tonne. After the first year, prices levelled off, averaging well below $2.205 per tonne.

Reductions under the Chicago ERMS program appear to be very cost effective based on the low and shrinking cost of allowances, but in reality, these allowance prices may not be tied to marginal compliance costs. Allowance prices per ATU averaged $76 in 2000, $52 in 2001 and are reported by Illinois EPA to have declined to $32 in 2002 (Kosobud et al, 2004). These allowance prices are well below the marginal cost of control in other regions, and are below an earlier 1996 estimate ($250 per ATU) by the Illinois EPA. However, these low ATU prices did not induce demand for ATUs and may actually indicate flaws in the market design and operation.

Box 3: Difficulties in Measuring Progress

In the ozone transport region, the 10 percent reduction in overall NO_x emissions did not translate into an equivalent reduction in ozone pollution, but may have prevented worsening pollution conditions. Between 1990 and 2001, the average ambient ozone conditions in the ozone transport region states were relatively constant, though weather differences make it difficult to detect trends. EPA recently began to apply meteorological adjustment technique to better account for year-to-year variations in ozone levels due to regional transport (EPA, 2004). Another difficulty in understanding progress relates to the choice of attainment metric. States must demonstrate attainment by looking at the second highest daily maximum 1-hour average concentration in a given year. This second-highest daily value fluctuates with a larger amplitude than, say, the 95th percentile (NRC, 2004: 203).

Ultimately, the aim of any ozone reduction program is improvements in health. Unfortunately, health impacts are difficult to assess for two main reasons. First, while there are significant overlapping data on disease over time in various populations and patterns of air pollution, air pollution accounts for only a small proportion of disease incidence. Second, while we can associate short-term changes in asthma emergency room visits with days with high measured concentrations of air pollutants, the underlying prevalence of asthma is changing, making it hard to detect effects of more gradual policy trends. To improve our ability to detect health trends resulting from reductions in emissions and ozone pollution, existing programs could be expanded to provide a coordinated approach to evaluating hazards and clusters of disease, and exposure and environmental factors. In addition, monitoring of actual human exposures rather than ambient emissions could be used to better understand pollutant trends (NRC, 2004).

6.2.2. Costs and Benefits

While no estimates appear available on the ex-post costs and benefits of US efforts to control ozone formation, in Table 6 we present some results of a recent review of the monetized costs and benefits of major EPA rules.

Table 6. Annual Benefits and Costs of Some Major EPA Rules, in million 2001 USD (OMB, 2003)

Rule	Benefits	Costs
Evaporative Controls	274-1.246	161-248
Onboard Diagnostic Controls	702-3.423	226
Reformulated Gasoline	213-723	1.085-1.395
Hazardous Organic NESHAP	600-2.700	292-333
Non-Road Compression Ignition Engines	617-3.253	29-70
Control of Emissions from Non-Road Large Spark-Ignition Engines and Recreational Vehicles	1.250-4818	192

6.3. Compliance and Enforcement

Many areas that had originally been classified as marginal or moderate nonattainment are now in attainment for the national ambient air quality standard. However, this success is balanced by continued nonattainment in areas in the serious and worse classification categories. As of 2004, many areas designated as moderate or marginal nonattainment for 1-hour ozone in 1991 have achieved attainment. Specifically, of the 31 areas originally designated as moderate nonattainment areas, 25 achieved attainment. Two of the areas remain moderate and three were redesignated to serious. Similarly, of the 42 areas designated as marginal, 24 have achieved attainment, one was redesignated moderate and the rest remain marginal areas. Progress has been less clear for the 24 areas originally designated as serious, severe or extreme. Despite the fact that the attainment deadline for "serious" areas was in 1999, only three out of 14 areas in this category have been redesignated to attainment. None of the severe or extreme areas have been so redesignated.

Reasons for this mixed performance relates in part to the structure of the air quality management process. The National Academy of Sciences cites bureaucratic overload, unrealistic deadlines, and overestimation of emissions benefits likely to be achieved by federal or federally-mandated measures (NRC, 2004).

The rate of compliance with a number of the specific regional and local programs have been high. Between 1999 and 2001, only 8 sources in the OTC NO_x Budget Program were in violation of their allowance holdings. The annual rate of compliance under RECLAIM was also high, ranging from 86 percent to 96 percent of total facilities in the period from 1994 to 2000 (EPA 2002b).

6.4. Administrative Feasibility

As mentioned in Case Study 1, the ease of administering SIPs, one of the main tools for addressing ozone pollution, has been highlighted as an area of concern.

6.5. Political Acceptability

Emissions control for ozone have always been a controversial issue. The mix between federal, state, and local regulation has been the subject of confrontation in efforts to control ozone formation. A number of the efforts to address ozone formation have, however, proved less controversial compared to other programs. For example, emissions trading has become an increasingly popular way to reduce regional, and even some local air emissions from point sources in the US. While there was some initial concern about how emissions trading would work and be perceived in the Northeast, states in the OTR developed a robust program that has achieved the desired emissions reductions along with a substantial level of compliance flexibility that presumably has led to cost savings. Emissions trading provided a way to minimize compliance costs and maintain competitiveness of regional power generators under an increasingly deregulated electricity market. In Chicago there were concerns about environmental justice that proved unfounded upon implementation of the program.

CASE STUDY 1 – ANNEX IV

THE CANADIAN APPROACH TOWARDS ACIDIFICATION, EUTROPHICATION AND GROUND LEVEL OZONE

4 October 2004

1. ADDRESSING ACIDIFICATION IN CANADA

1.1. Introductory Overview

Acid deposition in Canada has caused damage to Canadian ecosystems, including acidification of lakes and streams and damaging forest soils. As a result, Canada has undergone a series of initiatives to address acid rain, including through domestic and international actions to reduce sulphur dioxide (SO_2) and nitrogen oxide (NO_x) emissions.

1.2. Emissions Sources

In 1980, eastern Canadian SO_2 emissions were 3.8 million tonnes, mainly contributed by ore smelting, coal-fired power generators and natural gas processes (Environment Canada, 2004a). Industrial sources accounted for approximately 58 percent of Canadian SO_2 emissions, followed by fossil-fuelled electric utilities with 17 percent. During the same year, eastern Canadian NO_x emissions were at approximately 2.0 million tonnes, mainly contributed by the combustion of fuels in motor vehicles, residential and commercial furnaces, industrial and electrical-utility boilers and engines, and other equipment. Canada's largest contributor of NO_x was the transportation sector, which accounted for more than half of all emissions.

The influence of transboundary flows of SO_2 and NO_x from the United States into eastern Canada has been significant. More than half of the acid deposition in eastern Canada originates from US sources, and areas such as Muskoka-Haliburton and Quebec City receive up to 75 percent of their acid deposition from the United States (Environment Canada, 2004a). In 1995, the estimated transboundary flow of SO_2 from the US to Canada was between 3.5 and 4.2 million tonnes, which exceeded Canadian total emission of 2.7 million tonnes (Environment Canada, 2004a). Similarly, transport of NO_x emissions has been also observed.

2. LEGISLATION AND MEASURES IMPLEMENTED

2.1. Eastern Canada Acid Rain Program and UN-ECE First Sulphur Protocol

Canada made its first commitment to address acid rain problems in 1985 by initiating the Eastern Canada Acid Rain Program as a bilateral federal-provincial undertaking. The program's objective was to reduce wet sulphur deposition to a target of no more than 20 kg/ha/yr in the eastern provinces, a level estimated to protect moderately sensitive ecosystems (Task Group, 1997). To achieve this objective, the Program committed eastern Canada to cap SO_2 emissions at 2.3 million tonnes by 1994, a 40 percent reduction from 1980 emission levels. Seven provinces subsequently established individual emission targets and were responsible for developing and implementing pollution control measures. All seven provinces implemented 'command and control' strategy by assigning an individual emission cap for each large stationary source. Once emission caps were assigned, companies determined how they would achieve emission targets by the deadline.

For its part, the Canadian federal government was responsible for seeking reductions in transboundary SO_2 flow from the United States. That same year, Canada also signed the First Sulphur Protocol and committed itself to a permanent national cap of SO_2 emissions at 3.2 million tonnes by 1993.

2.2. Canada–United States Air Quality Agreement

In 1991, Canada and the United States signed the Air Quality Agreement to manage transboundary air pollution, starting with acid rain. The Acid Rain Annex committed eastern Canada to maintain emissions at 2.3 million tonnes of SO_2 from 1994 until 1999. It also reiterated its national 3.2 million tonnes cap established by the First Sulphur Protocol for the year 2000 and beyond. For the US, the Agreement enshrined its commitment under the 1990 CAA Amendments to reduce SO_2 emissions nationally by 40 percent from 1980 levels by 2010.

2.3. UN-ECE Second Sulphur Protocol

In 1994, Canada signed the Second Sulphur Protocol. In addition to reiterating the first Protocol, it established a geographically targeted emission reduction goal to achieve maximum environmental benefit. As a result, southeastern Canada was designated as a "Sulphur Oxide Management Area" (SOMA)[51] with an emissions cap set at 1.75 million tonnes by 2000. The Second Sulphur Protocol also committed Canada to work towards establishing and achieving critical loads for acid deposition problems. Such a commitment was timely – by 1994, Canada had planned to meet its goal of the Eastern Canada Acid Rain Control Program and therefore needed to develop a new strategy for the post-Program era. In addition, acid rain had remained a serious problem for Canadian ecosystems despite substantial progress made in reducing SO_2 emissions. As a result, federal, provincial and territorial energy and environmental ministers formed a multi-stakeholder taskforce, the "Acidifying Emissions Task Group," to develop a long-term, national acid rain strategy that fulfils Canada's domestic and international commitments.

2.4. Canada-Wide Acid Rain Strategy for Post-2000

The Acidifying Emissions Task Group released a report in 1997 that discussed the progress made to date and potential policy options for addressing remaining acid rain problems. In response, the Canada-Wide Acid Rain Strategy for Post-2000 was signed by federal, provincial and territorial Energy and Environment Ministers in 1998. The Strategy set the primary long-term goal of achieving critical loads for acid deposition across Canada and laid out a basic framework for acid deposition management. In addition to seeking further SO_2 emission reductions in the US, the Strategy committed four of the SOMA provinces (Ontario, Quebec, New Brunswick, and Nova Scotia) to set more stringent emission targets to meet the critical load. The strategy also sought to protect areas currently under the critical load and strengthen Canada's acid deposition monitoring and reporting system.

In 1999, the first year after the signing of the Strategy, federal, provincial and territorial governments focused their attention on a review of acid rain science and monitoring programs (Environment Canada, 2004a). The review identified a number of gaps in the existing monitoring network and research activities, and Environment Canada responded by increasing its funding for these program to rectify most of the deficiencies identified in the review. In addition, four SOMA provinces – Ontario, Quebec, New Brunswick and Nova Scotia – established new SO_2 emission targets that are 50 percent below those established under the former Eastern Canada Acid Rain Control Program.[52] These

---

[51] The SOMA includes major sources in Quebec, Ontario, New Brunswick, Nova Scotia, and Prince Edwards Island.

[52] Ontario announced a target of 50 percent reduction by 2015 (and has proposed to consult on advancing the timeline to 2010); Quebec, 40 percent reduction by 2002, and 50 percent by 2010; New Brunswick, 30 percent by 2005 and 50 percent by 2010; and Nova Scotia, 25 percent by 2005 and up to 50 percent by 2010.

jurisdictions are now developing and implementing measures to achieve these reductions (see box below).

Box 1: Example Provincial Efforts

The Ontario government introduced emissions caps for power plants with fossil-fuel combustion under its Emissions Trading Regulation, effective January 1, 2002, as part of its pollution control framework for electricity sector (CCME, 2004). When fully implemented in 2007, the caps are expected to reduce SO_2 by 25 percent and NO_x by 53 percent. Ontario also strengthened its Inspection and Maintenance (I/M) programs to further reduce NO_x emissions. In Quebec, Noranda Inc. has achieved 75 percent reduction of its SO_2 emissions from its Horne copper smelter in Rouyn-Noranda and remains committed to reducing up to 90 percent by 2006 (CCME, 2004). The Coleson Cove thermal generating plant, New Brunswick's largest source of electrical generation, is scheduled to switch to less-polluting fuel and to refurbish with extensive emission control equipment. Furthermore, many of the measures developed to reduce SO_2 and NO_x emissions further could be part of the jurisdictional implementation plans for achieving the Canada-Wide Standards (CWS) for PM and ozone (CCME, 2004).

2.5. Western Canada

Although the western provinces did not have acid rain problems and therefore did not have specific emission targets, they did adopt measures to control SO_2 emissions largely to protect air quality (Task Group, 1997). These were focused on the major sources of SO_2 such as oil sands, electric utilities, and natural gas plants which account for 75 percent of SO_2 emissions in three western provinces. For instance, British Columbia and Alberta both developed sulphur recovery guidelines for sour gas plants[53], and Alberta required its industrial facilities to use best available demonstrated technology that is economically achievable (Task Group, 1997).

2.6. NO_x

In its first approach to control acid rain problems in the Eastern Canada Acid Rain Program, Canada overlooked the contribution of NO_x emissions and did not implement any measures to reduce its NO_x emissions. However, Canadian NO_x emissions have been controlled under measures adopted for other air quality problems such as eutrophication or ground-level ozone. For instance, Canada's first commitment to control NO_x emissions was through the First NO_x Protocol that was intended to address eutrophication problems. Furthermore, when Canada committed to reduce 0.1 million tonnes of NO_x emissions from stationary sources from forecast levels by 2000 in the 1991 Canada-US Air Quality Agreement, Canada depended on its NO_x control measures that were already in place to address ground-level ozone problems. For this reason, measures adopted to reduce NO_x emissions will be discussed in the ground-level ozone section below.

3. ASSESSMENT OF THE EFFECTIVENESS

3.1. Environmental Effectiveness

3.1.1. Emissions

By 2000, Canada's SO_2 emissions of 2.5 million tonnes were 45 percent lower than 1980 levels (4.6 million tonnes) and 20 percent below the national target set for 2000 onward (Environment Canada, 2004b). Similarly, eastern Canadian emissions were 1.6 million tonnes, approximately 30 percent below the cap set by the Eastern Canada Acid Rain Program and extended by the Canada-US Air Quality Agreement's Acid Rain Annex. Although the decline in SO_2 emissions has slowed down,

---

[53] Sour gas refers to natural gas or gasoline contaminated with odor-causing sulfur compounds.

Canada has met all of its domestic and international commitments. Annual emissions trends for SO_2 are shown in Figure 1.

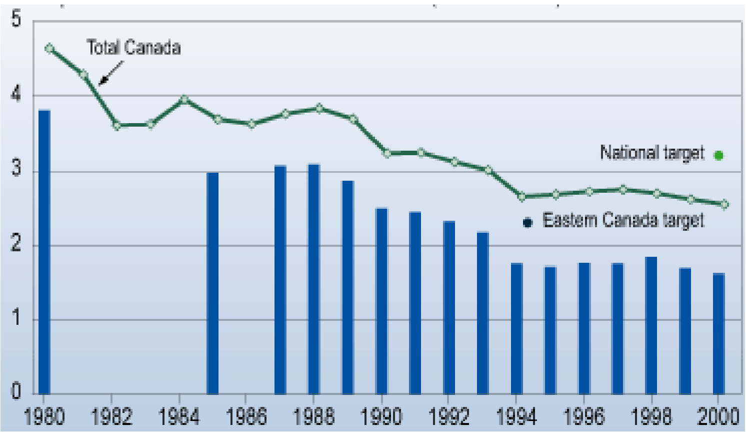
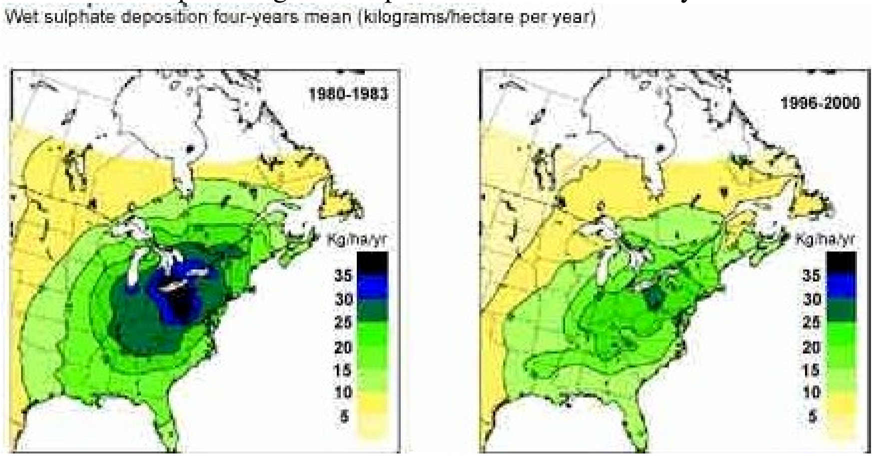


Figure 1. National and Eastern Canadian SO_2 emissions trends and targets during 1980 – 2000, million tonnes (Environment Canada, 2004b)

3.1.2. Impacts

The area in eastern Canada annually receiving 20 kg/ha or more of wet sulphate shrank considerably between the two periods 1980–1983 and 1996–2000. At the same time, the pattern of wet nitrate deposition changed very little (see Figure 2.). Although lake sulphate levels have declined along with the SO_2 emissions, improvements in lake acidity have been slower. Of the 152 lakes monitored in Ontario, Quebec, and the Atlantic Region since the early 1980s, only 41 percent have shown some improvement in acidity levels, while 50 percent have shown no change and 9 percent have become worse (Environment Canada, 2004b). There seems to be a time lag during which reductions in SO_2 emissions translate into widespread regional improvements in lake acidity.



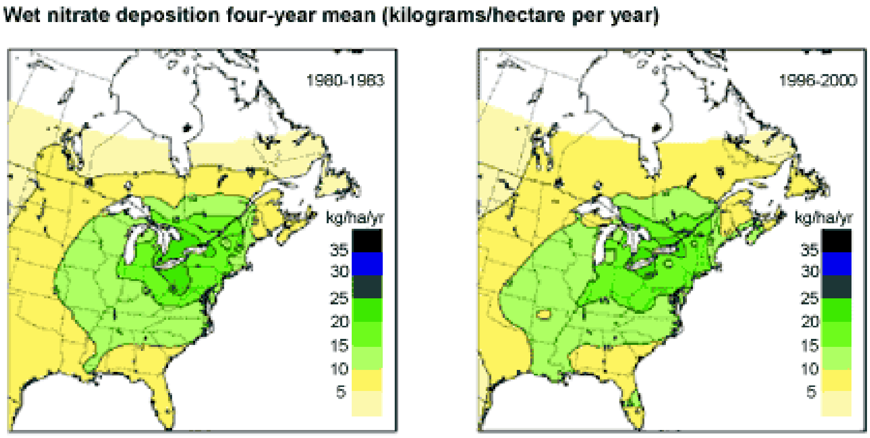

Wet nitrate deposition four-year mean (kilograms/hectare per year)

Figure 3. Changes in Wet Sulphate and Nitrate Deposition in Eastern North America between 1980-1983 and 1996-2000 (Environment Canada, 2004b).

3.2. Costs

There has not been a study looking at the cost effectiveness of Canada's various programs and measures used to reduce SO_2 emissions.

3.3. Compliance and Enforcement

Canada has met or exceeded all of its domestic and international commitments. By 1994, all seven provinces under the Eastern Canada Acid Rain Program successfully achieved or exceeded their individual SO_2 emission reduction targets. Collectively, they emitted 1.7 million tonnes of SO_2, considerably below the 2.3 million tonne cap and a 56 percent reduction from 1980 emission levels (Environment Canada, 1994). The successful reduction resulted from industrial process changes, scrubbers, fuel switching, and old plant closures (Environment Canada, 1994). Details of these SO_2 emission controls are described in Box 2, below.

Box 2. Industrial Action to control SO_2 emissions under the Eastern Canada Acid Rain Program (Source: Environment Canada, 1994)

Manitoba

- Manitoba's SO_2 emissions were 398 kilotonnes (kt), well below its target of 550 kt, due to process changes at two large point sources, which accounted for about 98 percent of total provincial SO_2 emissions.
- To reduce emissions, INCO Ltd. has optimized its processes to reject the sulphur-bearing ore fraction (pyrrhotite rejection) and the Hudson Bay Mining and Smelting Ltd. installed a new zinc pressure leaching plant, reducing SO_2 emissions by 25 percent.

Ontario

- Ontario's SO_2 emissions were 547 kt in 1994, 35 percent below its target of 885 kt, due to changes made in three smelters and Ontario Hydro which accounted for about 62 percent of total SO_2 emissions.
- INCO Ltd. slashed its emissions at the Sudbury complex by rejecting the sulphur-bearing ore fraction and by investing in new smelting technology and an acid plant. Falconbridge Ltd. modified its roasters and electric smelting furnace to increase energy efficiency and added an acid plant. Algoma Steel Inc. used low sulphur feed, halved its production, and recycled steel plant waste products. Ontario Hydro installed two scrubbers and switched to lower sulphur coal.

Quebec

- Quebec's SO_2 emissions were at 377 kt, well below its target of 500 kt.
- Noranda Metallurgy cut emissions by adding acid plants and other technology changes to its two smelters in Horne and Murdochville.

New Brunswick

- New Brunswick's SO_2 emissions were at 128 kt, well below its target of 175 kt.

- New Brunswick Power, which account for 70 percent of total provincial emissions, installed two scrubbers and increased the use of low-sulphur fuels in its production process. Pulp and paper mills modernized and added wood-waste boilers. Irving Oil increased production of low sulphur diesel fuel to help maintain its SO_2 emissions while expanding its operation

Nova Scotia

- Nova Scotia's SO_2 emissions were at 173 kt, under its target of 189 kt, due to changes made by Nova Scotia Power which accounts for 77 percent of the total SO_2 emissions.
- Nova Scotia Power commissioned a new clean-coal power plant designed to capture 90 percent sulphur in the fuel.

After exceeding its domestic commitments under the Eastern Canada Acid Rain Program, Canada continued to meet its international commitments made in the 1991 Canada-US Air Quality Agreement and the 1994 Second Sulphur Protocol. In 2000, both eastern Canadian and national SO_2 emissions were maintained well below the caps designated by the Canada-US Air Quality Agreement cap (CCME, 2002). Moreover, the four SOMA provinces kept their emissions 33 percent below the cap designated by the Second Sulphur Protocol. Summaries of Canada's domestic and international commitments and corresponding compliance are described in Table 1.

Table 1. Canada's Domestic and International Commitments and Compliance on SO_2 (CCME, 2002)

Commitment	**Compliance**
1985 Eastern Canada Acid Rain Program	
• Cap eastern Canadian SO_2 emissions at 2.3 mt by 1994 (40 percent reduction from 1980 level)	• In 1994, eastern Canadian SO_2 emissions were 1.7 mt (56 percent reductions from 1980 level).
1985 UN-ECE First Sulphur Protocol	
• Cap national SO_2 emissions at 3.2 mt by 1993 and beyond	• In 1993, national SO_2 emissions were approximately 3.1 mt.
1991 Canada-United States Air Quality Agreement	
• Cap eastern Canadian SO_2 emissions at 2.3 mt for 1994 – 2000 • Cap national SO_2 emissions at 3.2 mt by 2000 and beyond	• In 2000, eastern Canadian SO_2 emissions were approximately 1.6 mt. • In 2000, national SO_2 emissions were approximately 2.5 mt (20 percent below the cap).
1994 UN-ECE Second Sulphur Protocol	
• Cap SOMA SO_2 emissions at 1.75 mt by 2000 and beyond • Cap national SO_2 emissions at 3.2 mt by 2000 and beyond	• In 2000, SO_2 emissions in the SOMA were 1.2 mt (33 percent below the cap). • In 2000, national SO_2 emissions were approximately 2.5 mt.

3.4. Administrative Feasibility

Large sources of SO_2 in eastern Canada are few: seven smelters and three electrical utilities account for approximately 75 percent of total emissions in seven eastern provinces (Task Group, 1997). As a result, each province under the Eastern Canada Acid Rain Program had only two or three sources that could be assigned emission caps and maintained for compliance, as described above in Box 2. In addition, it was left to the individual sources to determine ways to meet the emission targets, therefore lessoning the administrative burden compared to assigning specific fuel or scrubber technology. Theoretically, these attributes should have eased the administrative feasibility.

3.5. Political Acceptability

Canada has a unique air quality management framework: federal, provincial and territorial governments cooperate to establish national and/or regional goals and objectives, while details of management strategies are often determined by cooperation between provincial governments and emissions sources under their jurisdictions. In case of the Eastern Canada Acid Rain Program, national goals were agreed to by the participating provinces, which later determined their individual goals and developed necessary measures. In case of the Canada-wide Acid Rain Strategy for Post-2000, a multi-stakeholder task group was formed by bringing together government officials, non-governmental organization and industry representatives. Although the Task Group was able to reach consensus regarding the long-term goal of achieving critical loads, it was unable to agree on specific targets and timelines. The SOMA provinces were subsequently responsible for developing specific targets that satisfy their environmental and industry group representatives. This multi-stakeholder process makes the resulting acid deposition management much more politically acceptable.

4. .ADDRESSING GROUND LEVEL OZONE IN CANADA

4.1. Introductory Overview

Canada has embarked on a wide ranging set of initiatives to address ground level ozone formation.

4.2. Emissions Sources

The primary sources of NOx include transportation sources, thermal electrical power plants, and certain industrial processes. In 1990, Canada's NO_x emissions totalled approximately 2.1 million tonnes. The majority of these emissions (61 percent) came from the transportation sector and 23 percent came from the industrial sector. Electric utilities contributed 12 percent, and the remaining 4 percent came from non-industrial fuel combustion. NO_x emissions from natural sources accounted for a small percentage of total emissions (WGAQOG, 1999).

The largest anthropogenic sources of VOC in Canada are industrial processes and transportation. In 1990, national anthropogenic VOC emissions were estimated at approximately 2.6 million tonnes, of which roughly a third (33 percent) came from industrial sources and another third (31 percent) from transportation sector. Application of surface coatings, general solvent use and other miscellaneous uses accounted for 26 percent of VOC emissions, and non-industrial fuel combustion added the remaining 11 percent. Biogenic VOC emissions in 1990 were estimated at 14.6 million tonnes, with vegetation contributing 97 percent of the total (WGAQOG, 1999).

5. LEGISLATION AND MEASURES IMPLEMENTED

5.1. National Ambient Air Quality Objective (1976)

Canada made its first attempt to address ground-level ozone problems by prescribing an air quality objective for ozone in 1976 under its Clean Air Act of 1973. This ozone objective was part of the Canadian National Ambient Air Quality Objectives (NAAQOs)[54] that were established to provide guidelines and targets (the maximum acceptable level) for federal, provincial, territorial and regional governments in air quality management (Health Canada, 2004). Based on the scientific information available at the time, the Canadian national objective for ozone was set at 82 ppb with a 1-hour averaging time (WGAQOG, 1999). In 1989, this objective was confirmed under the 1988 Canadian Environmental Protection Act (CEPA).

5.2. NO_x and VOC Protocols

In 1988, Canada signed the NO_x Protocol pursuant to the UN-ECE Convention on Long-range Transboundary Air Pollution and committed to freeze national NO_x emissions at the 1987 levels by

---

[54] NAAQOs included SO_2, CO, NO_2, total suspended particulates as well.

1994. In addition, in 1991 Canada also signed a VOC protocol and committed to freeze its national VOC emissions at the 1988 by 1997. The federal government also committed to reducing VOC emissions to 70 percent of 1988 levels by 1999 in the Vancouver-Lower Fraser Valley area and the Windsor-Quebec corridor by 1999 (Environment Canada, 1998).

5.3. CCME's NOx/VOC Management Plan

In 1991, the Canadian Council of Ministers of the Environment (CCME) agreed to a three phase NO_x and VOC Management Plan, designed to help all areas across Canada to meet the 1-hr ambient objective for ozone of 82 ppb. Phase One was composed of three initiatives: (1) a national prevention program to implement NO_x and VOC emissions reductions in selected industrial and mobile source sectors across Canada; (2) a regional remedial program to implement new NO_x and VOC emission limits in existing stationary facilities and develop local transportation management programs in smog problem areas; and (3) a scientific program to complete inventories, analyze the data, develop and validate models, improve monitoring networks, understand meteorological factors, and develop scenarios to assess future emission reduction requirements (AQC, 1994). Phase Two followed in late 1997, with a change in name from NO_x/VOC Management Plan to the Federal Smog Plan. Based on the NO_x/VOC Science Assessment, Phase Two added further NO_x and VOC reduction measures, included fine particulate matter, and attempted to integrate smog with other air pollution issues such as acid rain and climate change (GC, 1997).

5.4. Canada-wide Standards

In 1998, the federal government and provinces signed the Canada-wide Accord on Environmental Harmonization in 1998, hoping to improve their cooperation while managing regional air pollution issues such as ground-level ozone and smog. A key element of the Accord was a sub-agreement on Canada-Wide Standards (CWS) for key air pollutants. The federal-provincial Working Group on Air Quality Objectives and Guidelines set out principles for governments to jointly agree on priorities and developed the CWSs.

In June 2000, the federal, provincial and territorial governments except Quebec signed the CWS for particulate matter (PM) and Ozone. The CWS for $PM_{2.5}$ was 30 $\mu g/m^3$ averaged over 24 hours, and the standard for ozone was 65 ppb averaged over 8 hours, both to be achieved by 2010 (CCME, 2004). In addition, the Guidance Document on Achievement Determination was developed to elaborate on information, methodologies, criteria and procedures related to each of the basic elements of reporting.[55] Subsequently, the multi-stakeholder intergovernmental working group developed the Monitoring Protocol for monitoring program design and operation, ambient air quality trends analyses, regional source-receptor assessments, transboundary air quality analyses and implementation plan design in 2003. Similar to the Eastern Acid Rain Program, each jurisdiction is responsible for meeting the Standards for PM and ozone and reporting on achievement once the target dates are reached. Comprehensive reports on the Standards are to be produced every 5 years, beginning in 2006, along with annual reports on achievements and maintenance, beginning 2011.

5.5. The Ozone Annex to the Canada-US Air Quality Agreement

Later in 2000, Canada and United States signed the Ozone Annex to the Air Quality Agreement, committing to significant emission reductions of NO_x and VOCs. The Annex established a special region, known as the Pollution Emissions Management Area (PEMA), to pay greater attention because of its significant transboundary ozone problems (IJC, 2003). PEMA includes central and southern Ontario, southern Quebec, 18 US states, and the District of Columbia (see Figure 1). With signing of the Ozone Annex, Canada committed to (IJC, 2002):

---

[55] Annex B of the CWS for PM and ozone.

- Aggressive annual caps by 2007 of 39,000 tonnes of NO_2 emissions from fossil-fuel power plants in central and southern Ontario and 5,000 tonnes of NO_2 in southern Quebec;
- New stringent emission reduction standards regulated to reduce NO_x and VOCs from vehicles, including cars, vans, light-duty trucks, off-road vehicles, small engines, diesel engines, and fuels; and
- Measures required to attain the Canada-wide Standard for Ozone to address NO_x emissions from industrial boilers and to address VOCs emissions from solvents, paints, and consumer products.

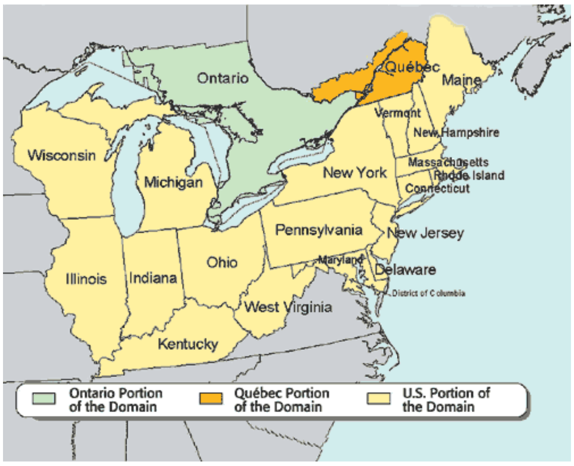


Figure 1. The Ozone Annex Pollutant Emission Management Area (IJC, 2003)

5.6. Interim Plan 2001 on Particulate Matter and Ozone

Since the signing of the CWS for $PM_{2.5}$ and ozone and the Ozone Annex, Canada has developed a number of measures to meet its commitments. In early 2001, the Canadian government announced the Action Plan on Clean Air with new funding of $120.2 million for the measures committed in the Annex (IJC, 2003). It contained planned actions in the areas of transboundary air pollution; air emissions from vehicles, engines, and their fuels; marine and aviation sources; emissions from industrial sectors; atmospheric science; science and monitoring networks; public outreach; and supporting actions on climate change (Environment Canada, 2001a).

Shortly after the release of the Plan, the Government of Canada also announced the Interim Plan 2001 on Particulate Matter and Ozone, which specified pollution control measures on transportation and industrial sectors, as well as action plans to improve emission inventory and monitoring (IJC, 2003). Some of the measures in transportation sector to emissions causing ground-level ozone in the Interim Plans are described in Table 1 (Environment Canada, 2001b).

Table 1. Regulations planned under the Interim Plan 2001 on Particulate Matter and Ozone (GC, 2003)

	Regulation		Subject	Description	Time
Vehicles & Engines	CEPA 1999	On-Road Vehicle & Engine Emission Regulations (SOR/2003-2)	LD vehicles & trucks	U.S. Tier 2 standards	2004
			HD vehicles & engines	U.S. Clean Air Nonroad Diesel Rule	2007
		Off-Road Small Spark-Ignition Engine Emission Regulations (SOR/2003-355)	Off-road gasoline-fuelled engines	19 kW (25 hp)	2005

Fuels	CEPA 1999	Sulphur in Gasoline Regulations (SOR/99-326)	Gasoline produced, imported or sold	Avg. 150 mg/kg Max. 300 mg/kg	2002
				Avg. 30 mg/kg Max. 80 mg/kg	2005
		Sulphur in Diesel Fuel Regulations (SOR/2002-254)	Diesel fuel used in on-road vehicles	Max. 15 mg/kg	2006
		Gasoline and Gasoline Blend Dispensing Flow Rate Regulations (SOR/2000-43)	Nozzles used to dispense gasoline (and blends) into on-road vehicle	38 L/min	2001

Currently, Canada is developing regulations on emissions from off-road compression-ignition engines (i.e. construction, mining, farming, and forestry machines)[56] and national VOC product standards for consumer and commercial products that align with those in the U.S.[57] In addition, federal and provincial networks of monitoring stations were expanded and refurbished to improve the National Air Pollution Surveillance (NAPS) Network and Canadian Air and Precipitation Monitoring Network (CAPMoN). Expansion of National Pollutant Release Inventory (NPRI) was announced to increase the number of pollutants and emission sources under the inventory system.

Considering that individual provinces differ in levels of ground-level ozone problems and subsequent regulatory goals and actions, the following discussion on implementation of the policies and measures is organized by provinces.

5.7. Provincial Responses

5.7.1. Ontario

In response to the 1990 CCME's Phase I NO_x/VOC Management Plan that identified the Windsor-Quebec corridor as the worst smog regions in Canada, the Ontario Ministry of the Environment started a collaborative planning process to take action o n smog in 1995. After a few years of multi-stakeholder process, Ontario released its first Smog Plan in 1998 and identified implementation, monitoring and reporting of emission reductions. Later renamed as the Anti-Smog Action Plan (ASAP), it is a 20-year plan and action agenda focusing on emission reductions for ozone precursors (NO_x and VOCs) and PM precursors (SO_2, NO_x, VOCs and particles). The goal of ASAP was to achieve, by 2015, a 75 percent reduction in the average number of times the 80 ppb 1-hr ozone Ambient Air Quality Objective is exceeded (OME, 1999). In order to achieve this goal, the ASAP participants endorsed a target of reducing the total provincial emissions of NO_x and VOC by 45 percent from 1990 levels by 2015 (see Table 2). In addition, ASAP committed to meet the CWS for $PM_{2.5}$ and ozone, as well as the Ozone Annex of the Canada-US Air Quality Agreement.

Table 2. Ontario's Anti-Smog Action Plan NOx and VOC reductions identified, planned or implemented as of March 1999, tonnes (OME, 1999).

	Baseline Emissions (1990)	45 percent Target (2015)	Reduction Amount Identified, Planned or Implemented
NOx	659,000	296,000	217 – 242,000
VOC	868,000	390,000	202 -228,000

---

[56] Off-Road Compressions-Ignition Engine emission Regulations (2004). Canada Gazette Part I. vol. 138, no. 19

[57] Notice of Intent – Federal Agenda on the Reduction of Emissions of Volatile Organic Compounds (VOC) from Consumer and Commercial Products (2004). National Office of Pollution Prevention, Ministry of Environment. Canada Gazette Part 1.

The following initiatives reduce smog-causing emissions, while also serving as building blocks for Ontario's implementation plan for meeting the Canada-Wide Standards for PM2.5 and O3 (OME, 1999):

- The province established caps with respect to NO_x and SO_2 emissions from Ontario Power Generation's (OPG) fossil plants and the electricity sector (*O. Reg. 397/01*). For large fossil plants, emission caps are reduced by 53 percent (from 2000 voluntary cap of 38,000 tonnes/yr) for NO_x and 25 percent (from the Acid Rain limit of 175 kt/yr) for SO_2, by 2007.
- The coal-fired Lakeview Generating Station in Mississauga is required to cease burning coal by April 2005 (*O. Reg. 396/01*).
- Ontario introduced an emissions trading system (*O. Reg. 397/01*).
- Inco and Falconbridge non-ferrous smelters, Ontario's largest emitter of SO_2, are required to reduce their allowable SO_2 emissions by 34 percent from their caps (265,000 and 100,000 tonnes, respectively).
- New or modified large boilers and heaters in industrial installations are required to reduce NO_x emissions by 29,000 tonnes by 2015.
- Drive Clean Program (*O. Reg. 361/98*), from 1999 to 2001, reduced smog causing vehicle emissions by 14,800 tonnes (15.2 percent) in Phase One (Greater Toronto Area and Hamilton). During its Phase Two (urban areas from Sarnia to Peterborough), smog-causing emissions were reduced by 3,500 tonnes (6.1 percent) in 2001. New I/M regulations for large diesel-powered trucks and buses were put in place in April 2004.
- Gasoline Volatility regulation *(O.Reg. 271/91)* limits gasoline vapour pressure during the summer and the Stage I Recovery of Gasoline Vapours in Bulk Transfers *(O.Reg. 455/94)*.

5.7.2. British Columbia

Airshed management has been most active in the Lower Fraser Valley where ground-level ozone problems have been more prominent than the rest of British Columbia. The Lower Fraser Valley Air Quality Coordinating Committee coordinates the efforts of the federal and provincial environmental agencies with those of the Greater Vancouver Regional District (GVRD) and Fraser Valley Regional District (FVRD). This Lower Fraser Valley coordinating mechanism has led to a number of initiatives (BCMWLAP, 2003):

- BC's AirCare Program has been in operation in the Fraser Valley since 1992. All light-duty vehicles were required to be tested for emissions inspection and maintenance. The AirCare On-road (ACOR) Program, which tested heavy-duty diesel trucks and buses, operated on a limited basis from 1996 until 2002, when its funding was suspended. After a review of its effectiveness, an expanded ACOR program started in 2004 to test both light and heavy duty vehicles.
- With its SCRAP program, BC provides financial incentives to take older vehicles off the road.
- GVRD manages emissions from more than 200 Lower Mainland commercial and industrial facilities through a permitting process. The permit specifies allowable emission levels and requirements for controlling, monitoring and reporting emissions. When a new permit is issued, or an existing one is amended, the permit limits are set by GVRD staff based on available pollution control measures (i.e. technology), permit limits under other jurisdictions, and the ambient air quality in the region.
- GVRD also charges industrial and commercial operations to partially cover the costs of monitoring and the compliance process. The fees are:
    - emission fee for all authorized air contaminants of $60 per tonne
    - annual administration fee of $1,000 per permit or approval
    - annual fees of $200 per year plus $20 per fuel dispensing nozzle for permits for motor vehicle fuel dispensing stations.

- GVRD administers emission regulations on non-domestic sources, such as ready-mix concrete and concrete industries, gasoline distribution terminals, gasoline bulk plants, fuel transfer vehicles, and automotive refinishing.
- While outdoor burning is banned in most areas, some municipalities allow burning during restricted periods.

6. ASSESSMENT OF THE EFFECTIVENESS

Unlike the measures implemented to address acid rain problems in Canada, most of the measures to address ground-level ozone formation that are currently in effect are scheduled to be fully implemented during the next 10 years.[58] Therefore, it is premature to assess the effectiveness of the Canadian approaches. Regardless, presented below is a short discussion of the emissions trends for NO_x and VOC, as well as ground-level ozone concentrations.

6.1. Environmental Effectiveness

6.1.1. Emissions

Total Canadian NO_x and VOC emissions have remained relatively constant since 1985 (see below).

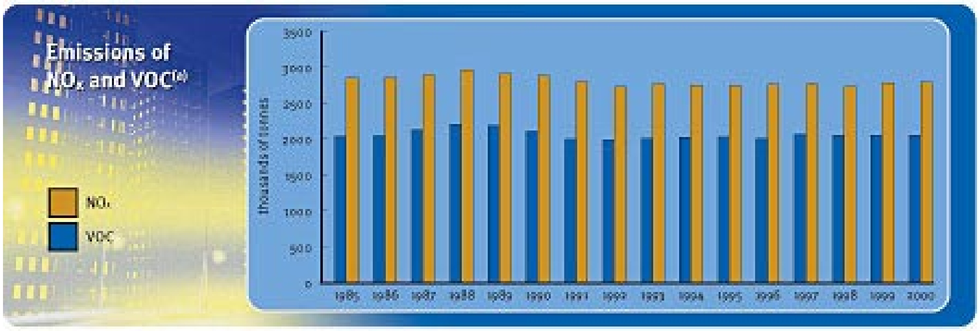


Figure 2. National NO_x and VOC emissions trends, 1985 – 2000 (Environment Canada, 2004a).

6.1.2. Impacts

Ground-level ozone levels have not changed significantly across Canada, although they tend to be higher east of the Manitoba/Ontario border (see below). Ground-level ozone is a concern principally in the Windsor–Quebec City corridor and, to a lesser extent, in the southern Atlantic region and the Lower Fraser Valley of British Columbia. Trends show that many areas record daily levels that can lead to adverse health effects (Environment Canada, 2004).

---

[58] Only NO_x and VOC protocols of the UN-ECE CLRTAP were completed, and Canada has met the commitments by stabilizing the NOx and VOC emissions at 1987 and 1988 levels, respectively.

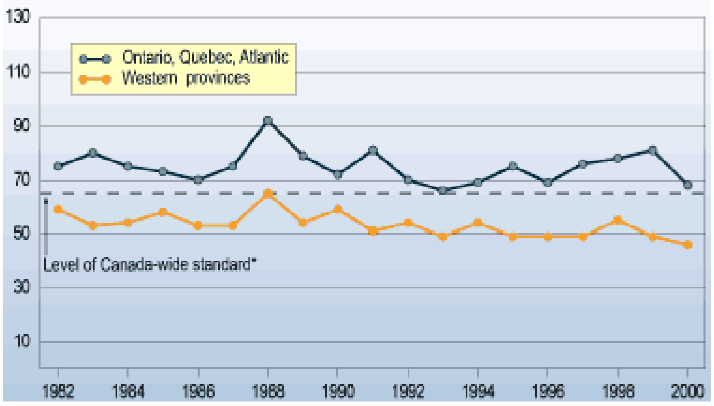


Figure 3. Average of peak concentrations of ground-level ozone in Canada during 1980, 1985 – 2000, parts per billion (Environment Canada, 2004b).

CASE STUDY 1 – ANNEX V

THE JAPANESE APPROACH TOWARDS ACIDIFICATION, EUTROPHICATION AND GROUND LEVEL OZONE

4 October 2004

1. ACIDIFICATION

1.1. Introductory Overview

Japan's air pollution control policies began in the 1960s after a series of high-profile environmental calamities, such as widespread sickness in Yokkaichi due to sulphur dioxide (SO_2) emissions. Whereas Japanese policy after the war had emphasized rapid industrialization and economic recovery rather than environmental preservation, public pressure obliged government responsiveness to environmental problems.

The first air pollution law, the Soot and Smoke Regulation Law of 1962, established a system for measuring SO_2 and NO_x emissions from stationary sources. This policy, and others passed in the early 1960s, addressed air pollution on a case-by-case basis without a central national program. In recognition of the inefficiency of a case-by-case policy and the pervasive nature of the air pollution problem, the Basic Law for Environmental Pollution Control was enacted in 1967 to establish general national principles and assign responsibilities to business and governments on various levels, with the ultimate goal of protecting human health. This law established ambient standards for SO_2, NO_x, CO, suspended particulate matter, and photochemical oxidants, which are of greater stringency than the European and US equivalents.

2. LEGISLATION AND MEASURES IMPLEMENTED

2.1. Air Pollution Control Law

In 1968, the Air Pollution Control Law was passed, establishing the basic framework for emissions regulation, with initial emphasis on SO_2. The law was amended in 1970, 1974, 1995, and 1996 to expand the range of pollution source (e.g., distributed generators were added in the 1990s) and address shortcomings (e.g., the "K-value" tool, discussed below). Under this law, prefectures were required to create a monitoring system to determine whether ambient levels of these pollutants complied with the 1967 law. Both stationary and mobile sources were subject to emissions controls as determined by the national government. New entrants into affected industries were subject to stronger standards than existing sources. Prefectures were permitted to establish more stringent standards than national levels. The law was amended to improve its legal structure in 1970 and for stationary sources the law has not been significantly modified. For mobile sources, which as described below represent a major air quality challenge in Japan, new approaches have been taken.

The Air Pollution Control Law uses four tools to limit SO_2 emissions – 1) regulations on sulphur content of fuels, 2) technology standards, 3) "K-value" regulation, and 4) total area-wide emissions control. A key benefit of the first and second tools is that by addressing fuels and technology, they have been applicable to both stationary and mobile sources. The remaining two tools have been applied only to stationary sources. Initially, the K-value approach was the preferred method but total area-wide emissions control proved necessary in some instances.

The K-value tool uses a detailed equation to proscribe "permissible limits for the quantity of sulphur oxides emitted according to the heights of smokestacks" (Nishimura, 1989, p. 208). As explained by the Osaka prefecture's APEC Virtual Center for Environmental Technology Exchange:

> "The K-value regulation is a method of regulating allowable emission level for sulphur oxides based on stack height. Specifically, the constant K of the equation is determined by the degree of concentration of facilities emitting smoke and soot in the area to ensure that concentration on the ground will be below a certain level. Regulation is tightened gradually while monitoring the actual

> enforcement of the regulation and the level of environmental pollution, with a view to reaching the environmental standard by the target year."[59]

A problem with the K-value tool is that in some cases, facilities may find constructing a taller smokestack to be more economical than reducing the actual sulphur content of flue gas. This transformed the SO_2 problem from a local to a regional issue. In response to this problem, the Air Pollution Control Law was amended in 1974 to add the total area-wide emissions control tool. As described by the Osaka prefecture:

> "Area-wide total pollutant load control is implemented as a solution for regulating pollutants from factories and other business establishments when it is difficult to attain environmental quality standards solely with conventional K-value regulation, due to concentration of factories and other establishments. To control the total emission of a pollutant in a certain area to the allowable level set for environmental conservation, portions of the total allowable emission (volume) are allocated among factories and other business establishments."[60]

The total allowable emission level is based on the quantity of each fuel that individual facilities use and the target level of total area emissions needed to achieve ambient targets. This equates to a maximum level of emissions per unit of fuel, which can be achieved by switching to lower sulphur fuels or by employing desulphurization technology.

Under the Air Pollution Control Law, the national government established ambient air quality standards for SO_2, NO_x, PM, and VOCs. Prefectures were charged with installing monitoring networks and for assigning emissions standards to affected facilities. The emissions standards were based on national formulas, but varied based on a particular region's geographic and meteorological characteristics. Companies and regulators worked together to determine the best approaches for emissions reduction and often included voluntary, negotiated agreements.

2.2. NO_x Regulation

Targeted NOx regulations came into effect in 1973 and pertained to stationary and mobile sources. The approach for NO_x from stationary sources was modelled after the total area-wide emissions control tool used for SO_2. Fuel and technology standards were the primary tools for addressing mobile source emissions. The policy for mobile sources has been amended numerous times but continues to rely on fuel and technology standards. However, growth in vehicle usage has outpaced improvements in efficiency. Mobile sources continue to be a pervasive source of NO_x emissions.

3. ASSESSMENT OF THE EFFECTIVENESS

3.1. Environmental Effectiveness

In considering the environmental impact of the Japanese efforts to address acidification, eutrophication and ozone formation, we consider to factors: trends in emissions and impacts.

3.1.1. Emissions

Japan presently has the third lowest SO_2 emissions intensity and lowest NO_x intensity among OECD countries (OECD, 2002b). Japan has seen tremendous reductions in SO_2 emissions since the 1970s and mixed results with NO_x. SO_2 emissions fell by 82 percent between 1970 and 1992 and by 3 percent (equivalent to 30,000 tonnes) between 1990 and 1999 (OECD, 2002b). The early reductions are credited largely to flue gas desulphurization technologies while the more recent reductions are credited to low sulphur fuels in the transport sector. NO_x emissions fell by 22 percent between 1970 and 1992,

---

[59] http://www.epcc.pref.osaka.jp/apec/eng/history/page/taiki_03.html - viewed April 1, 2004

[60] http://www.epcc.pref.osaka.jp/apec/eng/history/page/taiki_04.html - Viewed on April 1, 2004

and increased by 8 percent (equivalent to 145,000 tonnes) between 1990 and 1999 (OECD, 2002b). Early reductions are credited to flue gas denitrification technologies and the recent increase is associated with increased mobile vehicle use.

3.1.2. Impacts

In a study conducted in 1988, the Environment Agency (now the Ministry of Environment) found "no clear signs of adverse impact on the freshwater aquatic ecosystem, or on soil and vegetation" from acidification in Japan.[61] SO_2 emissions are also of little concern on a local level today. NO_x emissions, particularly on the local level, have continued to be a pervasive environmental problem.

3.2. Costs

In response to stricter standards enacted in the 1995 and 1996 amendments, the OECD estimates that over 320 billion JPY was spent by Japanese companies in 1996 alone on air pollution abatement and control (OECD, 2002b).

3.2.1. Technological Innovation and Improvement

Desulphurization and denitrification technologies receive most of the credit for reduced SO_2 and NO_x emissions from stationary sources. The OECD estimates that between 1990 and 1998 alone, desulphurization and denitrification capacity increased by 30 and 90 percent, respectively (OECD, 2002b). A greater reliance on natural gas and nuclear technologies for power generation has also been credited with delivering SO_2 and NO_x emissions reductions. Technological innovations for mobile sources (e.g., catalytic converters, fuel efficiency) have delivered environmental improvements on a per unit basis – though these improvements, particularly for NO_x, have been outpaced by demand growth. Low sulphur fuels have significantly reduced SO_2 emissions from mobile sources despite demand growth.

3.3. Compliance and Enforcement

In the wake of the high-profile environmental catastrophes in Japan resulting from industry negligence, regulated companies were eager to comply with their emissions obligations. Moreover, Japanese culture was amendable to environmental regulations, as company executives tend to take personal responsibility for their company's excesses. The original law's requirement that emissions data collected by the prefecture would be available for public review created further incentives for compliance. Japanese companies also saw opportunities to develop advanced technologies that could be sold to Europe and the United States. Since the policy was enacted, there has been only one case where a company has been prosecuted for non-compliance. In the end, compliance from large stationary sources was very high. Mobile sources have also been compliant with regards to fuel and technology standards; however, as mentioned above, growth in vehicle travel as outpaced efficiency gains.

Compliance has been aided by the vast monitoring network (over 1,700 general ambient monitoring stations and 400 roadside stations) that provide facility-specific data to government regulators. As of 2000, real-time monitoring data is available on the Internet.

Prefecture and local governments carry out periodic site inspections, which provide a further incentive for compliance. Over 80,000 were performed each year during the 1990s (OECD, 2002b). If companies are fined for non-compliance, they are subject to fines up to JPY 1 million and executives can be imprisoned up to 1 year. For mobile sources, vehicle inspections occur during vehicle

---

[61] http://www.env.go.jp/en/pol/wemj/acid.html, viewed on April 2, 2004. This study was followed by a five-year study beginning in 1993 that placed emphasis on SO2 deposition resulting from neighbouring countries' emissions (e.g., Korea and China).

registration as well as periodically thereafter (every 2 years for private vehicles, every year for commercial vehicles).

3.4. Political Acceptability

The Japanese approach to SO_2 and NO_x emissions control uses a command-and-control approach. Its political acceptability is connected to Japan's culture, which is conducive to this type of regulation. With the extreme nature of early environmental exacerbations, the public was highly supportive of environmental policies. Japan prides itself in the environmental improvements it has achieved.