Review of the Gothenburg Protocol

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Report of the Task Force on Integrated Assessment Modelling and the Centre for Integrated Assessment Modelling

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With contributions of the Coordination Centre for Effects (CCE) and the Meteorological Synthesizing Centre-West (MSC-W)

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Background document to UNECE document 'Review of the 1999 Gothenburg Protocol', Executive Body for the Convention on Long-range Transboundary Air Pollution (2007), ECE/EB.AIR/WG.5/2007/7. This background document is prepared by the Task Force on Integrated Assessment Modelling (TFIAM) and the Centre for Integrated Assessment (CIAM).

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CONTENTS

MAIN CONCLUSIONS

1. Emissions of all pollutants have shown a downward trend since the signing of the Gothenburg Protocol.

2. Deposition of acidifying substances in Europe has declined since the 1980s, with positive effects on the chemical composition of soil and lakes. Nitrogen deposition remains a widespread problem for European ecosystems. Despite reductions in precursor emissions, no clear downward trend in ozone indicators for human health and ecosystems can be detected in Europe.

3. Latest scientific findings suggest that current levels of exposure to fine particulate matter in Europe cause significant reductions in life expectancy. Secondary aerosols, formed from precursor emissions of SO_2, NO_x, VOC and NH_3 constitute a significant fraction of $PM_{2.5}$ in ambient air.

4. The benefits of current efforts under the Protocol exceed abatement costs. According to new scientific insights, however, efforts under the protocol lead to less improvement towards the ultimate objectives of the Protocol, in terms of the protection of ecosystems and health, than originally estimated.

5. To reach the ultimate goal of the Protocol - the protection of ecosystems and human health - further measures will be needed.

6. The effectiveness of the Protocol could be further improved by increasing the number of ratifications. There are strong synergies between the environmental objectives of the Protocol (i.e. reducing acidification, eutrophication, ground-level ozone) and a reduction of health impacts from fine particulate matter. Extending the remit of the Protocol to cover particulate matter could increase the cost-effectiveness of pollution control strategies.

7. In addition, the cost-effectiveness of further measures needs to be analyzed in close conjunction with other policy objectives, including those on climate change, energy security, transport and agriculture.

8. In addition to available end-of-pipe emission control measures, non-technical and local measures will be of increasing relevance, especially if multiple policy objectives are pursued. Emissions from international shipping will still offer a large potential for cost-effective abatement measures.

Other findings

1. It is estimated that most of the emission ceilings of the Protocol will be met by 2010. In many cases Parties have already reduced their emissions below the ceilings of the Gothenburg Protocol, often triggered by driving forces such as their accession to the EU, changes in the Common Agricultural Policy, or the implementation of EU directives on emission sources, air quality, nitrate in groundwater, etc. However, several Parties face difficulties in reaching their ceilings for NO_x emissions, partly because of improved base year emission inventories, lower than envisaged efficiencies of control measures in the transport sector, and partly because of lacking implementation of measures.

2. A review of the need and the cost-effectiveness of further measures should consider some new scientific insights:

- Knowledge on the health effects of long-term exposure to air pollution is now more robust than a few years ago. Cohort studies that became available after 1999 make it possible to quantify the loss of life expectancy due to exposure to fine particulates.
- While the analyses for the Gothenburg Protocol in 1999 considered only health effects of ozone for concentration levels exceeding 60 parts per billion, new studies point out the occurrence of negative health impacts at lower concentrations. These new findings would imply further abatement needs in order to achieve protection of human health.
- A more refined assessment of ecosystem-specific deposition results for sensitive ecosystems in higher excess deposition of acidifying and eutrophying compounds than estimated before.
- The 'ozone flux approach', which offers a biologically realistic description of the potential effects of ozone exposure to vegetation, could offer improved estimates of the damage to crops, forest trees and natural vegetation..
- There is increased awareness of the contribution of hemispheric emission sources to ozone levels in Europe, which may counteract the positive impacts of emission reductions in Europe.
- Improved emission inventories revealed additional sources that have not been accounted for in earlier estimates. This is of special relevance for the achievement of the emission ceilings for NOx.
- The real-life impacts of some emission control measures are lower than expected.
- In general, the assumptions on economic growth that were made for the Gothenburg Protocol have materialized, with few exceptions, in Eastern European countries.
- Despite current legislation, continued and even strengthened abatement efforts will be needed to keep emissions below the national emission ceilings agreed for 2010 in the longer term.
- There is a strong connection between greenhouse gas mitigation and the emissions of air pollutants.
- Some sectors have reduced their emissions more than others. For SO_2, the largest reductions were reached for large point sources, while for NO_x and volatile organic compounds (VOCs), emissions from the transport sector showed the strongest decline. NH_3 emissions from agriculture have decreased moderately. In contrast, emissions from international shipping have increased more rapidly than expected and are expected to surpass the total emissions from land-based sources of SO_2 and NO_x by 2020.
- Studies indicate that costs to realize the Protocol obligations could turn out to be lower than originally estimated. Economics of scale and technological progress can reduce real costs (estimated ex-post) by 50 percent compared to the ex-ante estimates[1]. In addition, some measures that are taken for other policy objectives (e.g. climate change, agriculture, biodiversity, water quality) reduce costs for air pollution control. Also the use of non-technical measures and structural changes lead to lower air pollution control costs than originally estimated on the basis of end-of-pipe measures.

1 Oosterhuis, F. (ed), 2006, Ex-post estimates of costs to business of EU environmental legislation, IVM, Amsterdam, April 2006, report commissioned by European Commission, DG Environment, Unit G.1 Sustainable Development & Economic Analysis, under a framework contract No ENV.G.1/FRA/2004/0081.

I INTRODUCTION

3. The 1999 Gothenburg Protocol is part of the stepwise process of the Convention on Long-range Transboundary Air Pollution (LRTAP) aiming in the long run at the achievement of protection of health and ecosystems by bringing deposition and concentrations of pollutants below critical loads and levels. As instruments, the Protocol employs national emission targets and sets of emission limit values that should accomplish by 2010 the agreed interim environmental objectives that are a step towards the long-term objective. Important criteria for the national emission targets in the Protocol have been cost-effectiveness, equity and environmental progress towards the long-term environmental objectives.

4. In order to maximize the cost-effectiveness of the national emission targets, a multi-pollutant/multi-effect approach has been chosen to identify, supported by the integrated assessment model RAINS, allocations of emission reductions across Parties to meet the agreed environmental interim targets at least cost. The RAINS model was developed by the Centre for Integrated Assessment Modelling (CIAM) hosted by the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. At that time, RAINS incorporated the best available knowledge of the late 1990s on the sensitivity of ecosystems, health effects, atmospheric dispersion, emission projections and abatement measures. Input to the RAINS model has been provided by a wide scientific network under the LRTAP Convention, including the various programme centres, task forces, co-operative programmes and expert groups under the EMEP Steering Body, the Working Group on Effects and the Working Group on Strategies and Review.

5. The purpose of this document is to review the effectiveness and sufficiency of the Gothenburg Protocol in the light of new scientific insights, recent trends and latest projections on economic activities.

Political developments

Since 1999, significant political developments occurred in Europe. The EU welcomed 10 new Member States on 1 May 2004 (Malta, Cyprus, Estonia, Latvia, Lithuania, Poland, Czech Republic, Hungary, Slovenia, Slovakia,) and Bulgaria and Romania joined the EU on 1 January 2007. Other countries, like Croatia and Turkey, have, at present, the status of accession countries. The new EU Member States had to implement the *'acquis communautaire'* that include inter alia the full EU air quality legislation, although sometimes with considerable transitional periods. The Accession Treaties of these countries also contain national emission ceilings for 2010 that are equal to the ceilings listed in the Gothenburg Protocol – where available.

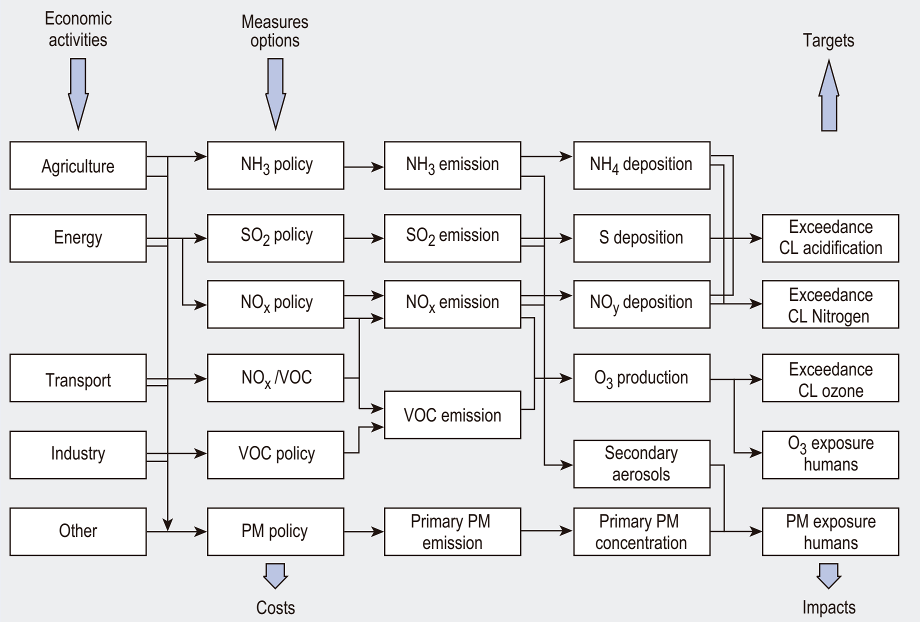
In a separate development, the geographical coverage of the Convention has been extended to the East with the accessions of Kazakhstan and Kyrgyzstan to the Convention in 2000 and 2001 respectively. There are now 51 Parties to the Convention including the European Community. Twenty-three Parties have ratified the Gothenburg Protocol so far (status April 2007). An action plan has been developed to strengthen further air pollution policies in Eastern Europe, the Caucasus and Central Asia (EECCA) and to encourage protocol ratifications by countries in this region. Furthermore, exchange of information has been initiated with Asian countries, including China and Japan, through the newly established Task Force on Hemispheric Transport of Air Pollution (TFHTAP).

Modelling multi-pollutant – multi-effect relationships

The RAINS (Regional Air Pollution Information and Simulation) model links sectoral developments and abatement measures for various pollutants with the environmental impacts of air pollution. RAINS considers acidification, eutrophication, ozone damage to vegetation, and health effects due to exposure to ozone and primary and secondary particulate matter. In 2007 the RAINS model has been extended into the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model that also includes greenhouse gas emissions and structural measures that affect the activity levels.

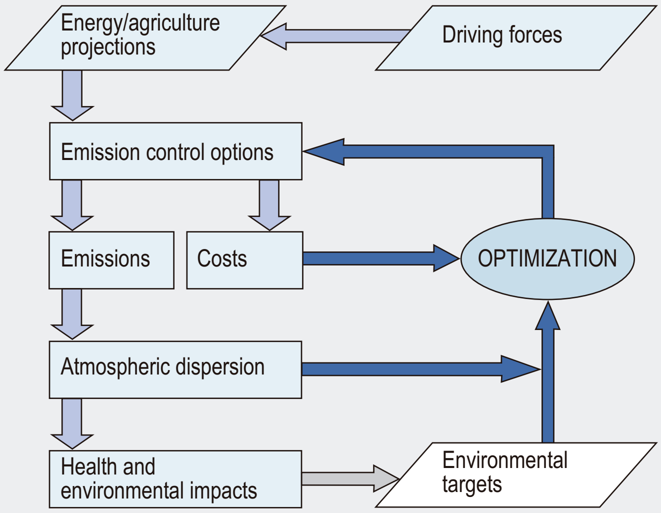
RAINS: a multi pollutant multi effect framework

http://www.iiasa.ac.at/rains



Review of the RAINS model

RAINS - structure



In 2004, a group of peer reviewers concluded that the RAINS model was fit for its purpose to support the review and revision of national emission ceilings, provided that uncertainties were sufficiently taken into account. RAINS should be seen as an analytical rather than a prescriptive tool. However, the reviewers noted that the RAINS development had not ended, and they recommended extensions to the local and hemispheric scales. As the reviewers stated a possible bias of RAINS towards emission reductions through add-on technical solutions, it was recommended to pay more attention to the potentials for emission controls offered by non-technical measures and structural changes in agriculture, transport and energy use. A systematic compilation of biases by the programmes under the Working Group on Effects (impact estimates) and Task Forces under the EMEP Steering Body (emission estimates and dispersion modelling) was also recommended. Parties to the Convention were asked to actively check and improve their data. CIAM was asked to further increase the transparency of the model by making input data and the model available via its website and to give users the possibility to provide feedback. These recommendations have been taken onboard in the work plan of the Convention. The local scale analysis has been included in the calculations based on the results of the City-Delta project. Pollution at hemispheric scale is addressed by the new Task Force on Hemispheric Transport of Air Pollution, and measures related to energy, transport and agricultural policies are now included in the new GAINS model. Uncertainties and possible biases have become a recurring issue in the meetings of TFIAM and the expert groups dealing with emission inventories, effects and atmospheric dispersion. After bilateral consultations between CIAM and more than 30 Parties, the GAINS emission databases are now consistent with national statistics on energy, agriculture and transport and with other international data sources (e.g. UNFCCC inventory on greenhouse gas emissions).

In 2007, a new version of RAINS has become available that provides an answer to much of the critique of the 2004 review. The development of this so-called GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model was financed by the Netherlands. Inter alia, GAINS allows better treatment of structural changes to form part of an emission control strategy. To analyze the cost-effectiveness of such structural measures, the optimization procedure has been changed. Instead of single pollutant cost curves, the GAINS optimization deals with individual abatement measures. These measures can have simultaneous effects on more than one pollutant. A review of the GAINS optimization procedure showed that the GAINS optimization in the RAINS-mode (that is without allowing for structural measures that change activity levels) produces the same results as the original RAINS optimization method. Information on the above mentioned reviews can be found at the website: http://www.iiasa.ac.at/rains.

Addressing uncertainty

The review of the RAINS model in 2004 recognised several simplifying assumptions and uncertainties that have impacts on model results. To safeguard the robustness of model findings, IIASA has undertaken extensive work to check the consistency and validity of input data and performed numerous sensitivity analyses with RAINS and its successor GAINS. These analyses include various sensitivity runs to investigate the robustness of policy relevant conclusions, including a relaxation of targets in "binding squares"[2] and changes in external projections such as shipping, energy use and agriculture. Modelling by EMEP has explored the sensitivity of the outcomes of atmospheric dispersion models to changes in global background concentrations, ecosystem-specific deposition rates, and the modelling of ozone deposition mechanisms. The inter-annual variability and extreme meteorological years might indicate potential impacts of a changing climate, although this effect is uncertain.

Inevitably, models dealing with the European scale require simplifications. For example, models derive future spatial emission patterns within countries by scaling them proportionally to the present emission distribution on a sectoral basis. In practice, however, countries have flexibility in how and where they achieve their emission reductions in order to meet their national ceilings. To examine uncertainties resulting from such generalizing assumptions, a growing number of countries are developing national scale integrated assessment modelling capabilities using more detailed data and spatial resolution, allowing comparison with national projections and exploring issues of scale and geographical factors within countries.

Such national integrated assessment models use emission projections broken down by sector or individual sources, and atmospheric modelling that resolves fine scale orographic effects and local scale dispersion. Such fine scale modelling coupled with more detailed critical load data can lead to enhanced estimates of exceedance and ecosystems at risk compared with European-scale modelling. Direct modelling of urban concentrations, validated against available monitoring data, indicate synergies between reduction of national emissions and targeted policies to comply with the limit values for NO_2 and PM_{10} of the Air Quality Directive of the EU - with particular emphasis on traffic emissions.

National integrated assessment activities have also demonstrated the potential for geographically targeted local measures to give greater improvement in environmental protection when coupled with changes in long-range transboundary transport than is indicated by RAINS. In this context there is now a substantial capability for more detailed modelling of energy, transport and agricultural scenarios and the impacts of shipping at the national scale to support the modelling of IIASA than at the time when the Gothenburg Protocol was negotiated. Comparison of RAINS results with national model results has been encouraged in the past and will also be important in future work for finding the most cost effective ways for protecting health and ecosystems.

2 Binding squares are areas where meeting European wide targets for the improvement of the environmental is only possible at very high costs. These areas would require application of measures at the end of the cost curve. A small relaxation of the European wide targets for these areas (what can be justified because of the uncertainties in depositions and estimated sensitivity of ecosystems) leads to significant cost savings.

II EMISSIONS, CONCENTRATIONS AND DEPOSITION LEVELS

Trends in emissions

6. Since the Gothenburg Protocol, our knowledge on the emissions has significantly improved by identifying a more complete range of emission sources, gathering more accurate statistics and resolving discrepancies between sectoral emission estimates across countries. The GAINS model can now reproduce national emission inventories of SO_2 and NO_x from national energy and agricultural statistics for almost all Parties with an uncertainty margin of less than 5% on average. For ammonia and VOC these uncertainty margins are slightly higher.

7. During the past decades emissions of SO_2, NO_x, VOC and particulate matter (PM) have declined substantially, and are expected to decline further with progressing implementation of current legislation on emission controls. In contrast, more modest reductions have occurred for NH_3. However, current levels of most emissions are two to three times higher than the pre-industrial levels. Parties that signed or ratified the Protocol exhibit much sharper emission reductions than the other Parties. For the latter group of countries, even an increase in emissions in the future cannot be ruled out.

8. According to the EMEP Meteorological Synthesizing Centre-West, in 2005 total emissions of SO_2 of all Parties to the Convention within the geographical scope of the EMEP model amounted to approx. 15 million tons, which constituted a decrease by 65% since 1990. Overall, this decline in 2004 already matches the reductions envisaged by the Protocol for the period 1990-2010. However, some 10% of the Parties that have ratified still need additional reductions to meet their individual ceilings for SO_2 in 2010. Total emissions of NO_x fell between 1990 and 2004 by 31% to 18 million tons. Thereby, a further 15% decrease in total emissions is necessary to reach the overall 2010 target. Half of the ratifying Parties need further reductions to meet their NO_x ceilings by 2010. Emissions of NH_3 were 7 million tons in 2004, 22% below the 1990 levels and close to the Protocol target. However, 15% of the Parties that have ratified have not reached the ceilings by 2004. Total emissions of VOC amounted to 15 million tons in 2004, which is 40% below the 1990 level, but 2-6% above the overall target of the Protocol for 2010.

9. As indicated above, substantial emission reductions occurred in the ECE countries within the EMEP modelling domain between 1990 and 2005. On a sectoral basis, the largest declines in relative and absolute terms occurred for emissions from power generation, which cut SO_2 emissions by 70% (or more than 16 million tons) and NO_x emissions by almost 50% (or 2.8 million tons). The majority of these reductions were caused by the economic restructuring in central and eastern European countries after 1990, which led to substantially lower coal consumption. In the EU countries, the introduction of end-of-pipe emission control measures yielded significant emission cuts. Furthermore, SO_2 emissions have been reduced in the domestic and industrial sectors as a consequence of the phase-out of coal. The transport sector, despite substantially increased traffic volumes, reduced its NO_x and VOC emissions by 28% and 66%, respectively. NH_3 emissions from agriculture and VOC emissions from solvents declined 20-30% (see *Table 1*).

10. An in-depth analysis of the factors that have caused the observed declines in SO_2 emissions in Europe suggests that, after the signature of the Gothenburg Protocol, about one third of the emission reductions were a consequence of the declines of energy-intensive industries that have occurred with the structural changes in the European economies. Another third is linked to (autonomous) replacement of coal and oil by cleaner fuels, while the remaining third was achieved through dedicated end-of-pipe emission control measures (see *Figure 1*).

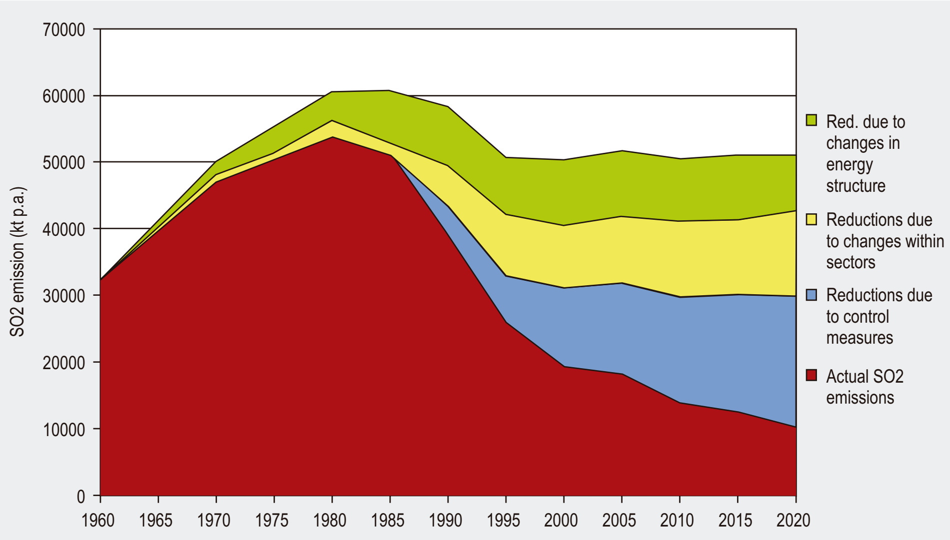


Figure 1: SO_2- emissions in Europe - 1960-2020: avoided emissions compared to hypothetical levels due to energy consumption growth. Emission reductions were caused by add-on measures, but also changes in the fuel mix and sectoral changes play a significant role. (Source: IIASA)

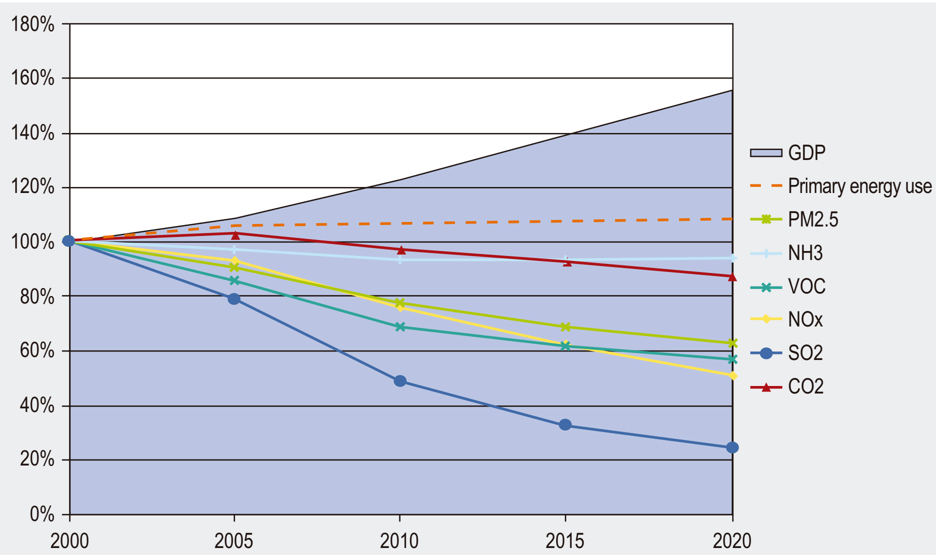


Figure 2: Trends in European emissions in comparison tot the trend in GDP and primary energy use. With current legislation emissions significantly decrease, with the exception of ammonia and carbon dioxide (source: IIASA)

11. Up to 2010, baseline projections developed with the GAINS model suggest, despite the envisaged economic growth, a continued decline of all pollutants as a consequence of ongoing structural changes in the energy and agricultural systems and the progressing implementation of emission control legislation (see *Figure 2*).

While most land-based emissions are expected to decline in the future, opposite trends are to be expected for the emissions from aviation and from international shipping (see textbox).

Table 1: Emission reductions between 1990 and 2005 by sector (in kilotons and percentage relative to 1990). Data source: GAINS model

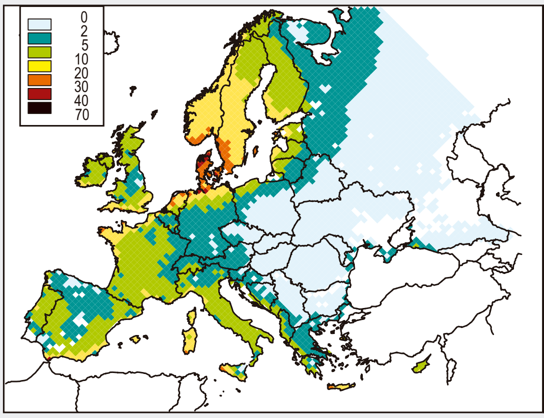
	SO_2		NO_x		NH_3		VOC	
1: Combustion in energy industries	-16688	-70%	-2821	-48%	0	4%	-38	-22%
2: Non-industrial combustion	-2321	-73%	-158	-16%	-15	-39%	-372	-23%
3: Combustion in manufacturing industry	-1809	-47%	-550	-24%	0	6%	-18	-19%
4: Production processes	-262	-25%	-162	-28%	-22	-21%	-202	-14%
5: Extraction and distribution	0	0	0	0	0	0	-323	-28%
6: Solvent use	0	0	0	0	0	0	-1631	-29%
7: Road transport	-409	-66%	-2261	-28%	49	241%	-4810	-63%
8: Other mobile sources and machinery	-320	-57%	-465	-17%	0	-23%	-255	-21%
9: Waste treatment	-1	-14%	-3	-16%	-6	-3%	14	10%
10: Agriculture	0	-4%	-1	-6%	-1349	-23%	-9	-5%
Sum	-21811	-65%	-6421	-31%	-1343	-22%	-7644	-40%

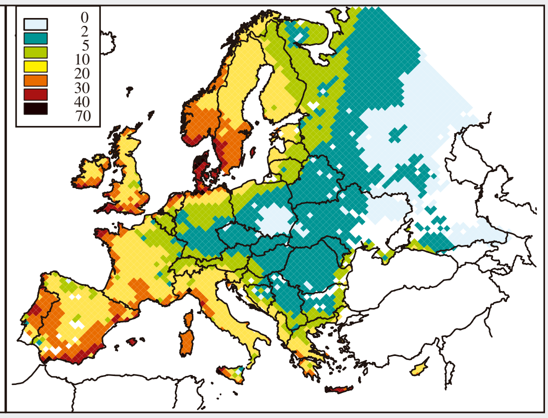
Modelling deposition of acidifying and eutrophying compounds

12. In the past five years, substantial improvements have been made in the modelling of air pollution. The EMEP Lagrangian dispersion model has been replaced by a more advanced Eulerian model. In addition to the different modelling concept, these models differ in their spatial resolution, which has been reduced from 150*150 km to 50*50 km. Also the modelling of deposition for different ecosystem types has been improved. The new, more realistic, approach consistently estimates higher deposition to forests compared to meadows and lakes.

Ship emissions: an outstanding problem

Sea shipping has been increasing. Ship emissions are not included in the Gothenburg Protocol. Ship emissions have been abated less than land-based sources. This has resulted in a gradual increase in the share of ships in the total emissions in Europe. In most coastal regions, the contribution of ships to the deposition of sulphur is expected to increase to 20-30% of the total deposition. The total emissions of NO_x and SO_2 from ships will, around 2020, almost be equal to the total land-based emissions. Many marine emission reduction options for SO_2 and NO_x are more cost-effective than additional measures on land. Additional technical and non-technical measures to reduce ship emissions could significantly reduce the total costs of meeting the environmental ambitions of the Protocol.[3] Further emission reductions on ships are currently being discussed within the International Maritime Organization (IMO).





Percent of sulphur deposition from international sea shipping in 2000 (left) and in 2020, with current legislation (source: IIASA)

3 Cofala, J, *et al*, Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive, EC Service Contract No 070501/2005/419589/MAR/C1, IIASA, 2007

Modelling population exposure

13. In the past years, work has progressed to improve the modelling of the exposure of the European population to PM and ozone. On the basis of the City-Delta project, relationships were derived to estimate the difference between rural background PM concentrations and the background in urban areas, taking into account factors like the size of the city, the population density, urban emissions and meteorological parameters such as wind speed[4]. Low-level emissions from traffic and domestic heating contribute relatively more to the exposure of the population in cities than emissions from high stacks, making measures aimed at these sectors also more effective in reducing population exposure.

14. For SO_2, the exposure of the urban population from high stacks emissions has decreased further in the past decade. The fraction of urban population that is exposed to SO_2 concentrations above the EU limit values decreased to less then 1%. As such the EU limit value is close to being met. For NO_2, PM_{10} and ozone the trends are less clear. In North and Western Europe a decrease in the most extreme ozone values has been observed between 1990 and 2005. There is strong evidence that the lower percentiles in the ozone values in densely populated polluted areas of Europe have increased, in particular during winter. An important contribution to this upward trend comes from a reduced titration effect in response to the reduction of European NO_x emissions. Across Europe, populations are exposed to levels of air pollution that are higher than the air quality standards set by the EU and the World Health Organization (WHO). This occurs predominantly within urban/suburban areas, although for PM_{10} and ozone, such exposure also takes place in rural areas. None of the ozone exposure indicators used by the European Environment Agency (EEA) show a discernable declining trend: average, as well as peak concentrations, remained fairly constant.[5]

15. Measurements at sea and on mountain tops suggest that background ozone in the EMEP region has increased by up to 5 ppb per decade since the 1970s. In the Mediterranean basin annual average background ozone concentration range between 30 and 35 ppb, and 20-25 ppb over Northern Europe. Since a considerable share of these concentrations is caused by emissions from other continents, possible increases in ozone precursor emissions in other world regions would have immediate impact on European ozone levels.

Review of the EMEP model

In 2003, a review of the EMEP Eulerian model was organized under the auspices of the Task Force on Measurements and Modelling (EB.AIR/GE.1/2004/6). For sulphur and nitrogen deposition, it was concluded that the model was suitable for the calculations of source receptor relationships for sulphur and nitrogen deposition aimed to support European air quality strategies. For ozone, it was also concluded that the model was suitable for the assessment of vegetation exposure and for the assessment of human health effects on the regional scale. For particulate matter, it was concluded that the model underestimated observed PM_{10} and $PM_{2.5}$ due to an incomplete description of relevant processes and emissions. However, the model was able to calculate the regional component of main anthropogenic PM fractions with enough accuracy for the assessment of the outcome of different control measures, i.e. secondary inorganic aerosols and some primary components for which emission inventories were sufficiently reliable. Model inter-comparisons showed that the EMEP model was also state of the art for PM.

Important limitations to a sound understanding of PM dispersion were identified. These include: uncertainties in emission totals (both from anthropogenic and natural/biogenic sources), the chemical composition of emissions, the contribution of particle-bound water to PM mass, and the mechanisms behind secondary organic aerosol formation. Understanding the chemical composition of ambient PM is a prerequisite for evaluating and improving the EMEP model in this area.

4 Thunis, P., Rouïl, L., Cuvelier, C., Bessagnet, B., Builtjes, P., Douros, J., Kerschbaumer, A., Pirovano, G., Schaap, M., Stern, R. and Tarrason, L. (2006). Analysis of model responses to emission-reduction scenarios within the CityDelta project. *Atmospheric Environment*.

5 See: EEA, Europen exchange of monitoring information and State of the Air Quality in 2005, ETC/ACC Technical Paper 2007, in prep.; and: Steinar Larssen and Kevin Barrett (eds), Air Pollution in Europe 1990-2004, NILU, in prep.

Urban scale exposure to particulate matter

Health impacts are most pertinent in urban areas where a major share of the European population lives.

Current European integrated assessment modelling describes the long-range transport of pollutants with a spatial resolution of 50 * 50 km. Obviously, with such a resolution assessments would systematically miss the higher pollution levels in European cities and therefore underestimate population exposure.

To correct for local emissions, a methodology has been implemented in the GAINS model that starts from the hypothesis that urban increments in $PM_{2.5}$ concentrations originate predominantly from primary PM emissions from low-level sources within the city. The formation of secondary inorganic aerosols, as well as the dispersion of primary $PM_{2.5}$-emissions from high stacks, is reflected by the background concentrations computed by the regional-scale dispersion model.

Based on the results of the City-delta model intercomparison, which brought together the 17 major European urban and regional scale atmospheric dispersion models[6], a generalized methodology was developed to describe the local increments in $PM_{2.5}$ concentrations in urban background air that originate from urban emission sources. Mathematical relationships associate these urban increments in PM levels with the spatial variations in emission densities of low-level sources in a particular city as well as city-specific meteorological and topographic factors.

In GAINS, urban background $PM_{2.5}$ concentrations within cities are then derived by correcting the PM concentration value computed by the 50*50 km regional dispersion model with a "city-delta", i.e. the increase in concentrations due to emissions in the city itself. Thereby, the City-delta approach redistributes concentrations resulting from local emissions within the 50*50 km grid cell along the variations in emission densities of the low-level sources, while in regional-scale calculations this contribution is uniformly spread out over the whole 50*50 km grid.

16. In the model calculations made for the preparation of the Gothenburg Protocol, (hemispheric) background ozone levels have been assumed to remain constant in the future. As a result, a potential increase in the background concentrations in the northern hemisphere as a consequence of increasing emissions outside the Convention domain would diminish the ozone reductions that have been envisaged from the agreed measures in the Protocol. emissions outside the Convention domain would counteract the ozone reductions that have been envisaged from the agreed measures in the Protocol.

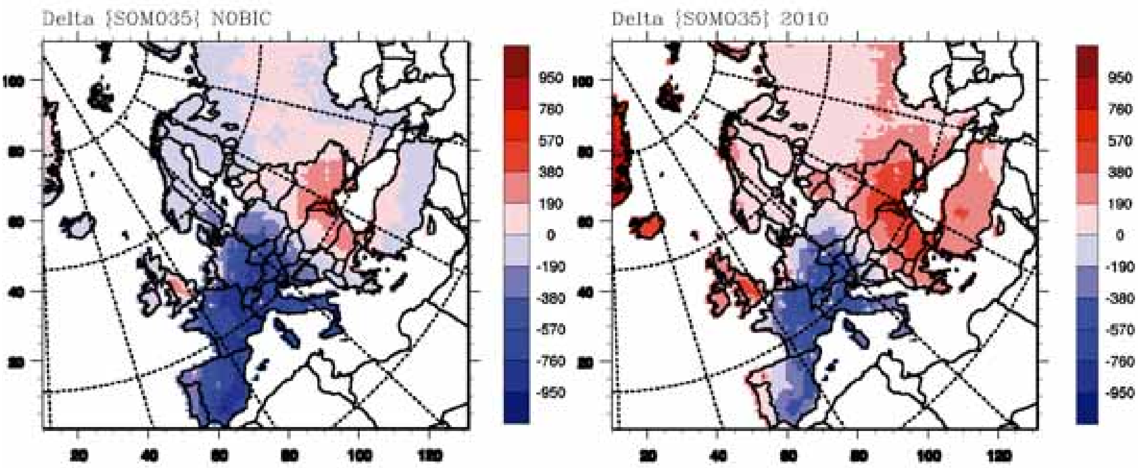


Figure 3: Hemispheric ozone developments could increase the challenge. The left figure shows the calculated effects of current legislation in Europe on the changes in the sum of the mean ozone values over 35 ppb in rural areas in 2020 assuming no increase in hemispheric concentrations. The right figure shows that when rising emissions of CH_4, VOC and NO_x at the global scale are assumed this would diminish the expected improvements in the sum of the maximum daily 8-hour mean ozone values over 35 ppb (SOMO35). Source: EMEP/MSC-W

6 Thunis, P., Rouïl, L., Cuvelier, C., Bessagnet, B., Builtjes, P., Douros, J., Kerschbaumer, A., Pirovano, G., Schaap, M., Stern, R. and Tarrason, L. (2006). Analysis of model responses to emission-reduction scenarios within the CityDelta project. Atmospheric Environment submitted.

III EFFECTS ON HUMAN HEALTH, NATURAL ECOSYSTEMS, MATERIALS AND CROPS

17. Critical loads for acidification and eutrophication for all of Europe were updated in 2006 by the national focal centres and compiled by the Coordination Centre for Effects (CCE). With these data, GAINS estimates that, for 2020, critical loads for acidification will still be exceeded at 11 percent of the European ecosystem area, compared to 34 percent in 1990 and 20 percent in 2000. Exceedances of 200-500 eq/ha[7] per year of the critical load for acidification will remain in Germany, Poland, the Czech Republic, Austria, France, Benelux and Denmark and will be more than 1000 eq/ha per year in the border region of Germany and the Netherlands. These revised estimates are now less optimistic than what was assumed

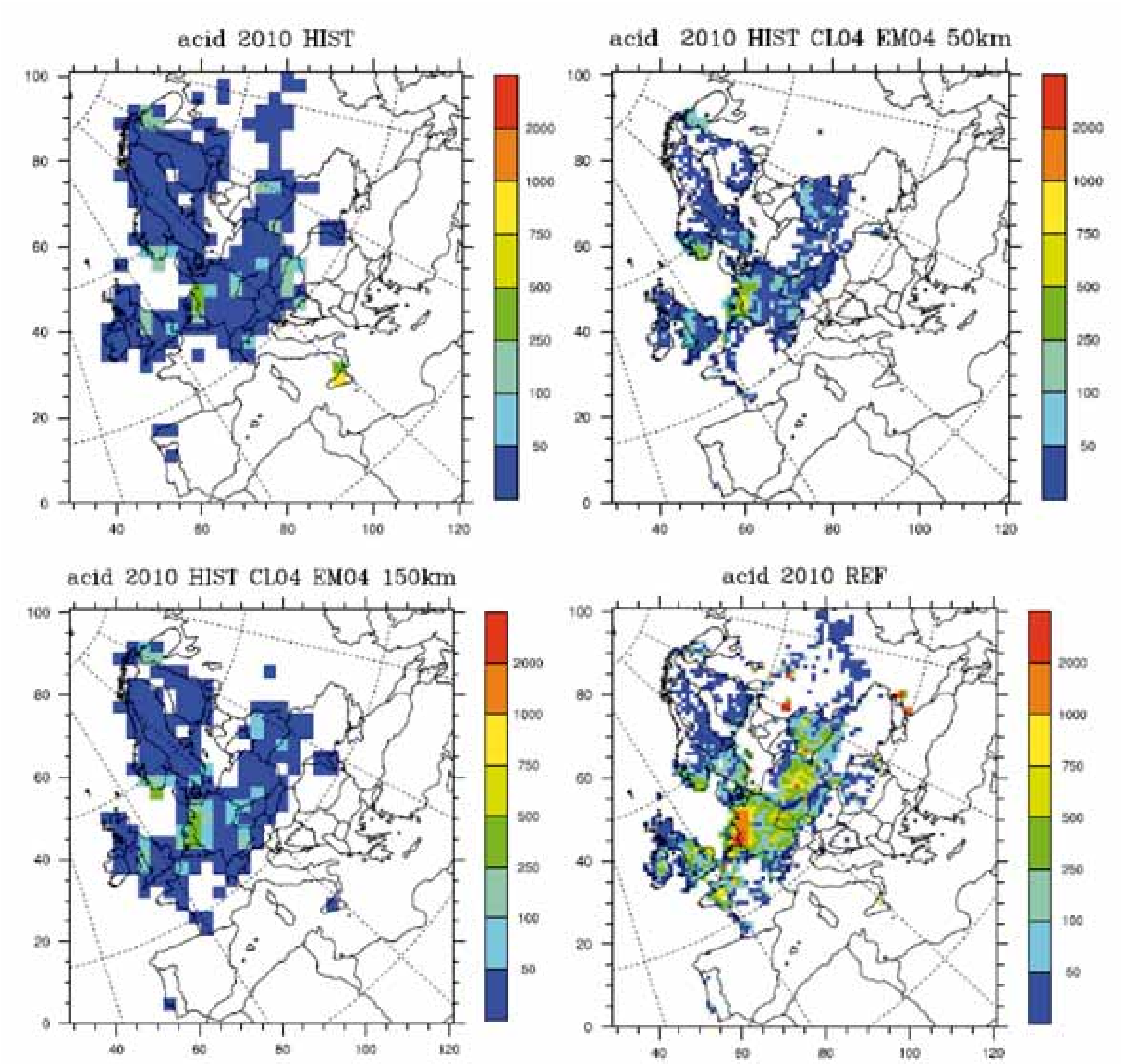


*Figure 4: Factors changing ecosystem risk estimates: accumulated exceedance of critical loads of acidity (in eq/ha/yr) in 2010 according to the methodology used for the Gothenburg Protocol (top left), with the new critical loads (bottom left), the fine resolution of 50 * 50 km grid with the new critical loads (top right) and the use of ecosystem dependent deposition rates (bottom right). Source: CCE/EMEP-MSC-W*

7 The term "equivalent" is used as a measure for acidity. 1 equivalent is equal to 1 mol of charge.

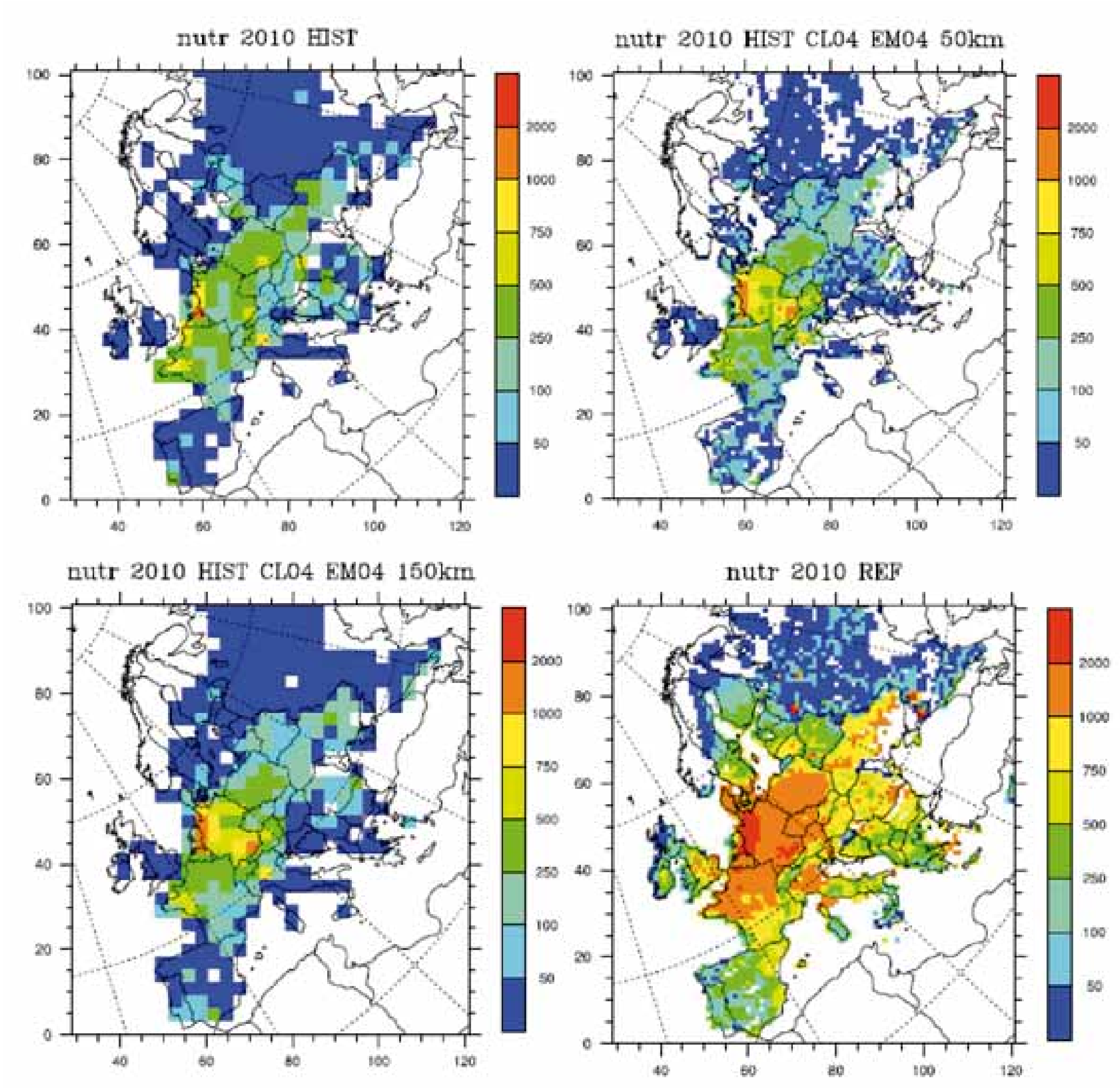


*Figure 5: Factors changing ecosystem risk estimates: exceedance of critical loads of nitrogen (in eq/ha/yr) in 2010 according to the methodology used for the Gothenburg Protocol (top left), with the new critical loads (bottom left), the fine resolution of 50 * 50 km grid with the new critical loads (top right) and the use of ecosystem dependent deposition rates (bottom right). Source: CCE/EMEP-MSC-W*

when the Gothenburg Protocol was negotiated. At that time, contemporary knowledge of critical loads, emission data and atmospheric dispersion characteristics suggested for the year 2010 excess of the critical loads for acidification to occur at only 3 percent of the European ecosystems area (declining from 16 percent in 1990). The most important factor leading to the revised, less optimistic estimates relates to the improved modelling of sulphur and nitrogen deposition processes over forests, which now takes into account the systematically higher deposition of pollutants over rough surfaces (*see Figures 4 and 5*).

18. The refined assessment indicates higher and more widespread, but less uniform risks of, eutrophication across Europe. It is now estimated that by 2020 nitrogen deposition will exceed critical loads for eutrophication for 53 percent of the ecosystem area, while for the Protocol negotiations excess of critical loads was envisaged for only 20 percent of the ecosystems area. Nitrogen deposition in 2020 is expected to exceed the critical loads typically by 250-750 eq/ha per year, but can reach values of more than 1000 eq/ha per year in areas with high cattle densities.

Remaining problems

19. Since 1990, the deposition of acidifying compounds has decreased substantially and, with full compliance with the obligations of the Gothenburg Protocol, a further decrease in the coming years is expected. While, compared to 1990s, there is now less risk of acidification to waters and forests following the decline of sulphur and nitrogen emissions, current deposition is still well above the levels needed for recovery of ecosystems (see *Figure 6*).

20. Slow progress in reducing nitrogen deposition maintains the widespread risk for detrimental impacts of eutrophication, such as the loss of biodiversity. In 2000, the forest area with nitrogen deposition exceeding the critical loads for eutrophication was four times larger than the forest area with excess acid deposition.

21. For ground-level ozone, only limited progress can be detected based on the recent risk indicators addressing human health (SOMO35) and vegetation (the ozone flux metrics), and there is no clear picture on the development expected for the next few years.

Ecosystem damage due to acidification and eutrophication

22. The Working Group on Effects, its six International Cooperative Programmes (ICPs) and the Task Force on Health provide the necessary information on effects on human health and the environment to assess the effectiveness of abatement measures. It was found that excess sulphur and nitrogen deposition, as well as acidified soils, imply hazards to forest ecosystems and unbalanced tree nutrition. The vegetation species composition can be linked to nitrogen deposition[8]. There is increased evidence that high nitrogen deposition could damage forests and trees due to diseases, frost, droughts and storms[9].

23. The monitoring activities under the ICP Forests and ICP Integrated Monitoring have confirmed the positive impacts of the declines in sulphur emissions over the last decade on deposition in forests ecosystems. Observations at almost all monitoring sites of ICP Waters and ICP Integrated Monitoring have shown a clear decrease in sulphate in surface waters since 1990. This has resulted in less acidic surface waters, which are now less toxic to biota, and has led to the first signs of biological recovery. No trends, however, have been detected for nitrogen deposition. Nitrogen continues to accumulate in most forest and catchment soils with risks for biodiversity changes; and nitrogen deposition remains in many regions twice above the critical loads for eutrophication. Thus, the recovery achieved by the decline in sulphur deposition could be offset by the net acidifying effects of nitrogen leaching following nitrogen saturation caused by further nitrogen deposition.

8 Sverdrup, H S. Belyazid, B. Nihlgard, L. Ericson, Modelling change in Ground Vegetation Response to Acid and Nitrogen Pollution, Climate Change and Forest Management at in Sweden 1500–2100 a.d., Water, Air & Soil Pollution, Vol 7, nr 1-3, p163-179, 2007

9 De Vries, W., J. Kros, J.W. Erisman and G. J. van Duinen, 2004. Adverse impacts of elevated nitrogen use. In J.W. Erisman et al (2004): The Dutch Nitrogen cascade in the European perspective.

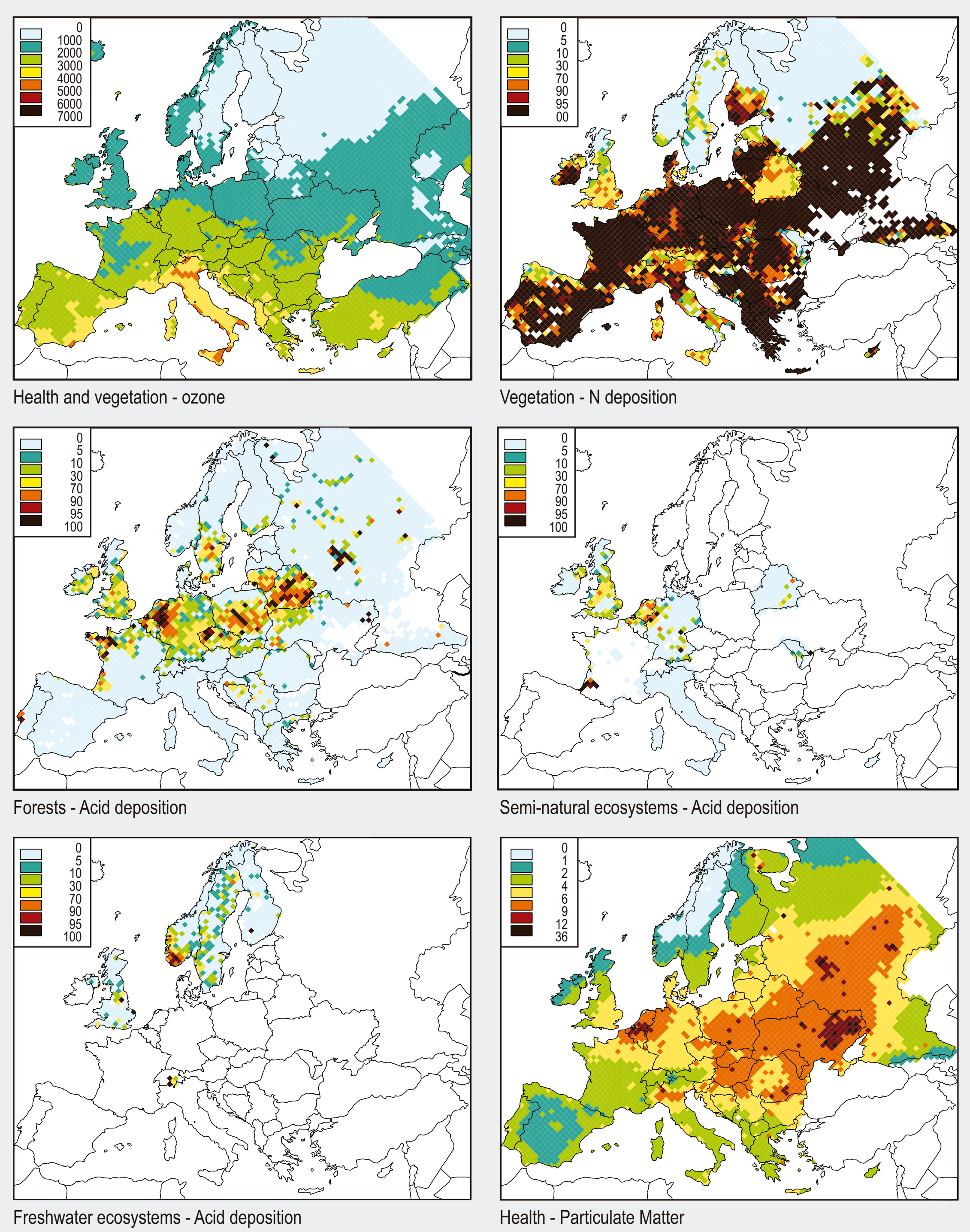


Figure 6: Remaining problems in 2020: ozone exposure will be highest in the Mediterranean (see SOMO35 values at the top-left). Nitrogen will remain a widespread problem (see % of ecosystems not protected at the top-right). Acidification of forests and nature areas will still occur in the central zone of Europe (see % of ecosystems not protected in the middle figures). Acidification of lakes will remain problem is parts of the United Kingdom and Scandinavia (see % of ecosystems not protected at the bottom left) and significant health risks from anthropogenic PM exposure will remain in Eastern and central Europe and in parts of the Benelux and Italy (see reduced life expectancies in months at the bottom right) (Source: IIASA).

Recovery targets of ecosystems

Critical loads represent a steady-state maximum level of a pollutant input that can be tolerated by an ecosystem without leading to negative impacts in the long run. However, actual ecological damage occurs as a consequence of dynamic chemical and biological processes, with historic depositions, stocks of chemicals and delay times as important factors.

The modelling of the dynamics of ecosystems recovery from acidification achieved a major breakthrough in 2004. A Europe-wide dynamic acidification modelling framework is now ready to quantify damage and recovery times. Current dynamic models can address nitrogen and carbon cycles and eutrophication for alternative deposition scenarios, but they require further testing prior to regional application.

With the insights from these new dynamic models, risks of continued exceedance of critical loads and levels can now be better assessed than in 1999. According to these models, acidified forest and surface water sites in many regions in Europe would need many more decades for chemical and biological recovery even if the Protocol was fully implemented. In addition, ecosystems may not recover to their original status.

The decrease of emissions of acidifying substances has also slowed the pace of depletion of the soil buffering capacity. At current rates, it takes now five times longer for actual damage to forests to become visible than in the 1980s. However, the current situation is still not sustainable. In (valuable) nature areas where the buffering capacity is already depleted, recovery from acidification requires a period of deposition below the steady-state critical loads. Dynamic acidification models could assist to explore the levels of deposition that would allow chemical recovery within a chosen time period.

For nitrogen the situation is more complex. Field experiments under the Swedish ASTA programme have highlighted the effects of additional nitrogen loading on changes in forest vegetation in unpolluted areas. Analyses in the Netherlands and the United Kingdom have shown that with increased availability of nitrogen more rare species become endangered, and dominant species more abundant. However, biodiversity is not only influenced by nitrogen, but also by changes in land use, climatic conditions and forest and nature management.

The political choice of biodiversity-based targets loads could be complex. Within the EU, characteristic species of Natura-2000 areas could be chosen as the basis for such an approach.

In the past years more information has become available on the linkages between the nitrogen and the carbon cycle. Field experiments have analyzed the effect of whole tree harvesting (a new forestry practice to increase the use of biomass in electricity and heat production) on nitrogen dynamics. Biomass production in forests for energy production requires more nitrogen and this could therefore influence the choice of the target loads for nitrogen.

Ozone damage to crops and natural vegetation

24. After 2000, use of the ozone flux approach, a new concept for critical levels of ozone for crops and forest trees, has been developed (see textbox). This method links ozone effects to a plant's uptake of ozone through its stomata on leaf surfaces.

25. ICP Vegetation has observed continued damage to vegetation from ozone across 17 European countries between 1992 and 2006. In dry grasslands in the Mediterranean and in Southern Germany, as well as in Alpine grasslands and temperate shrub heath land, combined effects of ozone and nitrogen have been detected. The observed trends reflect the spatial and temporal variation in ozone concentrations, without marked declines or increases over time. Estimates of the economic costs of ozone damage to crops and timber in 1990 amounted at € 30 bn per year. Current estimates quantify the economic damage of ozone to crops in the year 2000 at roughly € 7 bn per year or 2% of the agricultural production in Europe.

Ozone flux modelling

The flux-based approach takes into account the uptake of ozone by plants dependant on the humidity and is believed to be biologically more realistic than other approaches. For crops, this flux approach is now an accepted method and is incorporated within the Mapping Manual of the LRTAP Convention. The flux method for forest trees has been conceptually accepted, though further work is needed to develop the methods for practical application.

The flux approach results in a more widespread spatial distribution of ozone damage to vegetation and crops over Europe compared to the traditional concentration-based AOT40[10] approach, which indicated ozone damage as a mainly Southern European problem.

The Europe-wide assessment of ozone effects has been improved with the harmonized land cover database, merged from land cover information of the Coordination Centre for Effects, the CORINE (Coordination of Information on the Environment) programme and the Stockholm Environment Institute. This harmonization has aligned work under the Working Group on Effects and the EMEP Steering Body. The same map is being used to calculate critical loads and levels for terrestrial and aquatic ecosystems, and to calculate ecosystem-specific deposition of sulphur and nitrogen and ozone fluxes to vegetation.

10 AOT40 is the accumulated ozone concentrations over a threshold of 40 parts per billion

Health effects of air pollution

26. In recent years, the Joint Executive Body/WHO Task Force on Health has reanalyzed the evidence on health impacts of ozone and particulate matter (PM).

27. Based on recent studies reported in the scientific literature, a new indicator for health impacts from ozone has been developed. These studies have shown effects at ozone concentrations below the previous guideline of 120µg/m³ (60 ppb) and no clear evidence of the existence of a threshold for effects. There is clear evidence for acute health effects occurring below 60 ppb (measured as the daily eight-hour mean concentration), the threshold which was used for the preparation of the Gothenburg Protocol. While a clear threshold cannot be discerned from the available studies, a pragmatic choice of a 35 ppb threshold has been made to account for increasing uncertainties on the effects at lower concentrations. This new SOMO35 (sum of the 8-hour mean ozone values over 35 ppb) indicator gives higher weight to medium ozone concentrations occurring over the entire year compared to the earlier AOT60 (accumulated concentration over a threshold of 60 ppb) approach, which put more emphasis on episodes with peak ozone.

28. The 2005 update of the global WHO Air Quality Guidelines recommends an 8-hour mean concentration of 50 ppb as the air quality guideline level. In the Guidelines, it is also acknowledged that health effects will occur below this level in some sensitive individuals. Based on time-series studies, the estimated number of premature deaths attributable to ozone at the guideline level of 50 ppb would be 1-2% higher compared to a level of 35 ppb (which is the base level for the SOMO35).

29. The SOMO35 health effects indicator, combined with the results of the Eulerian EMEP model, yields larger health impacts in Southern Europe compared to the earlier calculation method, which suggested more damage in the North-western and central parts of Europe.

30. Calculations using the SOMO35 indicator (i.e. the sum of maximum daily 8-hour means above an ozone concentration of 35 parts per billion) result in over 20,000 premature deaths annually across Europe attributable to ozone. While there are indications that the number and magnitude of ozone peak concentrations have declined over the last decade, current policies are not expected to significantly change long-term exposure and health impacts in the future (see *Figure 7*).

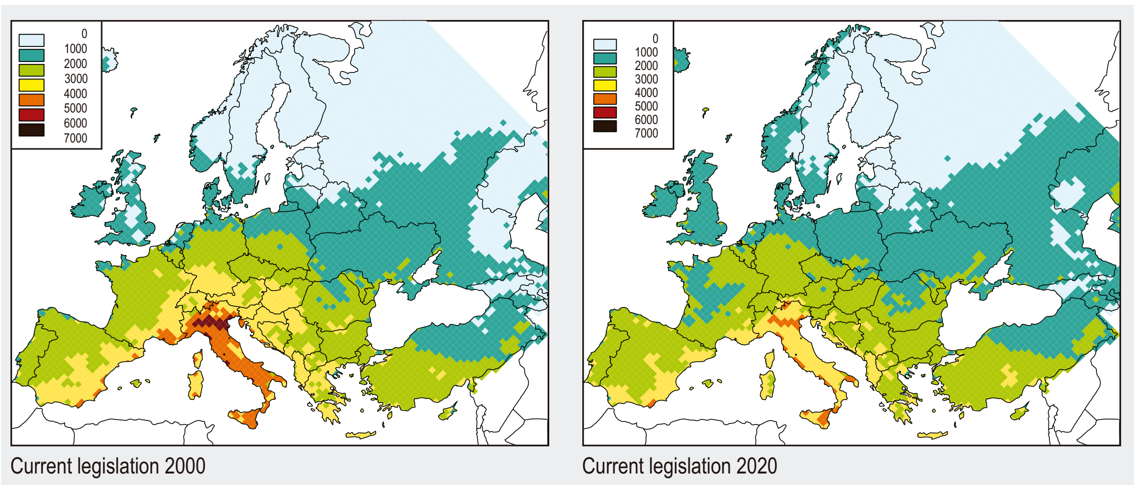


Figure 7: Ozone exposure in 2000 and 2020, with current legislation. Sum of the mean ozone values over 35 ppb in rural areas (SOMO35)

Non-linear ozone effects of NO_x reduction

A wide body of scientific literature has highlighted important non-linearities in the response of ozone concentrations to changes in the precursor emissions, most notably with respect to the levels of NO_x emissions. It has been shown that, at sufficiently high ambient concentrations of NO and NO_2, lower NO_x emissions could lead to increased levels of ozone peaks. In earlier analyses for the negotiations of the Gothenburg "multi-pollutant/multi-effect" Protocol in 1999, the RAINS model reflected this non-linear response through source-receptor relationships that describe the effect of NO_x emission reductions on accumulated ozone concentrations above 60 ppb in form of quadratic polynomials[11]. A re-analysis of the latest Eulerian model results with a focus on the likely emission levels for the year 2020 suggests that such non-linearities will become less important for three reasons: (i) In 2020 "current legislation" baseline NO_x emissions are expected to be 50 percent lower than in the year 2000. (ii) The chemical processes that cause these non-linearities show less effect on the new long-term impact indicator (SOMO35) than for ozone peak concentrations; and (iii) such non-linearities diminish even further when population-weighted country-means of SOMO35 are considered. It was found that within the policy-relevant range of emissions (i.e. between the "CLE" (current legislation) and the "MTFR" (maximum technically feasible reduction) levels anticipated for 2020), changes in the SOMO35 indicator could be described sufficiently accurate by a linear formula.

The relationship between ozone formation and climate change has been the subject of several recent and ongoing studies. Meteorological changes as well as rising global emissions of NO_x, methane (CH_4) and carbon monoxide (CO) could cause increasing ozone concentrations throughout the Northern Hemisphere and higher peak concentrations at higher latitudes.

31. Scientific knowledge at the time of the Gothenburg Protocol negotiations allowed an assessment of health impacts of particulate matter only for acute effects attributable to the exposure to secondary inorganic particles that are formed from SO_2, NO_x and NH_3 emissions. In the meantime, numerous scientific studies have created a large body of evidence for statistically robust associations between premature mortality and the long-term population exposure to total particulate matter.

32. The recent WHO systematic review points to the health significance of fine particles, i.e. those with a diameter less than 2.5µm ($PM_{2.5}$). In particular, the effects of long-term PM exposure on mortality seem to be associated with $PM_{2.5}$ rather than to coarser particles. There is currently insufficient scientific evidence for robust conclusions about the potencies of different particle constituencies and characteristics on health impacts.

33. The largest epidemiological long-term study in the United States that has involved several 100,000s of people for more than 20 years found an increase of 10 µg/m³ $PM_{2.5}$ in ambient air associated with a six percent higher risk for premature mortality. Comparable results have been obtained by smaller European cohort studies. Applying the same relative risk figure to European conditions, the GAINS model computes for the year 2000 an average loss of statistical life expectancy of approximately 8.6 months, or more than 214 million lost life years for the EU-27 and Norway. This is considerably more then the 5.6 million lost life years that were estimated during the preparation of the Gothenburg Protocol, which included secondary inorganic particles only and quantified only acute (short-term) mortality.

34. The critical role of $PM_{2.5}$ for health impacts implies that the long-range transport of primary and secondary particulate matter makes a significant contribution to acute and chronic health problems in Europe. At urban background stations, emissions of NO_x, SO_2 and NH_3 can contribute 20-50% to the anthropogenic fraction of $PM_{2.5}$ concentrations. In busy streets the contribution from local sources (especially of carbonaceous aerosols) is higher.

35. Current legislation on the emissions of primary PM and PM precursors is expected to reduce the health impacts by about one third by 2020. Further measures are readily available that could further reduce emissions and thereby the health impacts.

11 Heyes, C., Schöpp, W., Amann, M. and Unger, S. (1996). A Reduced-Form Model to Predict Long-Term Ozone Concentrations in Europe. WP-96-12. International Institute for Applied Systems Analysis, Laxenburg, Austria.

36. In most countries, concentrations of anthropogenic $PM_{2.5}$ have considerable transboundary origin of about 60% on average. Natural sources such as Saharan sand storms also contribute to hemispheric PM concentrations. They are limited to specific meteorological episodes.

Materials damage

37. Declining concentrations of acidifying air pollutants resulted in decreased observed corrosion of materials at the ICP Materials sites - by about 50% on average in 1987-1997. The corrosion rate of carbon steel decreased further in 1997–2003, though the rates for zinc and limestone increased slightly. Nitric acid and particulate matter currently contribute to corrosion in addition to sulphur dioxide. Exceedances of tolerable levels of corrosion for cultural heritage materials were frequent. Particles contain also soil materials, and the tolerable PM_{10} level for soiling of three selected materials is 12–22 $\mu g/m^3$ based on reasonable cleaning intervals. For 1990, it was estimated that air pollution caused € 1.8 billion of materials damage. Emission reductions envisaged under the Gothenburg Protocol are expected to improve materials damage across Europe by more than € 1 billion.

IV EMISSION CEILINGS OF THE PROTOCOL

Policy conclusions

- For the EMEP region as a whole, emission reductions between 1990 and 2010 are comparable with the emission reductions envisaged by the Protocol.
- No Party that ratified seems to have serious problems in meeting the NH_3 ceiling in 2010.
- For SO_2 and VOC only a few Parties that ratified need additional policies to meet the ceilings.
- For NO_x half of the Parties that ratified need additional policies. In six countries the NO_x ceiling would be met a few years after 2010 without additional measures. Reasons for not meeting the ceilings are: revised base year emission inventories (e.g. emissions from the off-road sector have been added), higher real life emissions (e.g. from Euro-2 and -3 vehicles) or lacking implementation of measures. One party will not meet the NO_x ceiling because this is based on the energy sold instead of the energy used.
- In a significant number of countries, projected emissions for 2010-2020 will be more than 50% below the ceiling of the Protocol. These overachievements result inter alia from lower coal use compared to what was expected when the national emission ceilings were negotiated.
- No significant difference can be detected in the efforts between countries that ratified and the other Parties that only signed the Protocol, as most of them are EU Member States and subject to the National Emissions Ceiling (NEC) directive of the EU. Some Parties that signed but have not ratified would have no problem with any of the emission ceilings.
- There are significant differences, however, to the efforts of other Parties to the Convention. Emissions of countries that did not sign or ratify the Protocol are projected to increase in the future.

Implementation

38. For the review of the Gothenburg Protocol, the EMEP Centre for Integrated Assessment Modelling (CIAM) updated emission inventories and projections of anthropogenic activities for all Parties of the Convention in the EMEP domain. Bilateral consultations were held with national experts from 30 countries, including 25 EU countries, Norway, Switzerland, Russia, Ukraine and Belarus. As a consequence of the economic restructuring in Central and Eastern European countries, projections provided by national experts for 2020 imply substantially lower emission figures than the earlier 2010 estimates if stricter emission control legislation is assumed. However, for the non-EU countries in Central and Eastern Europe the projections provided by experts in the bilateral consultations, and in particular the assumption that stricter air pollution control legislation will be implemented, were not officially confirmed. A more conservative emission projection was therefore used for this review.

39. Emission projections for sea regions for 2020 exceed the levels anticipated for 2010, essentially due to the increased volume of shipping.

40. Under the assumption that current legislation will be fully implemented, most Parties to the Gothenburg Protocol will meet their ceilings (see *Table 2*). For NO_x, 9 out of 21 European countries that ratified

Table 2: Implementation of the Gothenburg Protocol. Projected emission reductions, significant exceedances of emission ceilings (> 5% = red shading) and significant overachievements (> -50% = green shading)

	Baseline based on national projections				Implementation of the protocol							
	reduction 2000-2020				exceedance ceiling 2010				exceedance ceiling 2020			
	SO2	NO_x	VOC	NH3	SO2	NO_x	VOC	NH3	SO2	NO_x	VOC	NH3
Bulgaria	86%	33%	36%	2%	-49%	-41%	-28%	-38%	-87%	-59%	-54%	-37%
Cyprus	84%	42%	61%	3%	-54%	-21%	-57%	-20%	-80%	-35%	-62%	19%
Czech Republic	29%	40%	37%	8%	-17%	4%	-12%	-22%	-37%	-34%	-33%	-24%
Denmark	25%	41%	49%	42%	-65%	33%	9%	-16%	-62%	-1%	-16%	-23%
Finland	23%	39%	43%	14%	-43%	-1%	-14%	-1%	-49%	-24%	-30%	-3%
France	25%	41%	52%	7%	24%	38%	-14%	-16%	23%	1%	-22%	-17%
Germany	30%	47%	41%	26%	-15%	12%	4%	-14%	-20%	-14%	-14%	-19%
Hungary	86%	43%	27%	-16%	-74%	-30%	-11%	-9%	-88%	-46%	-14%	0%
Latvia	-30%	8%	37%	-14%	-79%	-50%	-58%	-67%	-82%	-63%	-68%	-67%
Lithuania	19%	16%	38%	-6%	-73%	-53%	-42%	-56%	-73%	-62%	-54%	-53%
Luxembourg	58%	48%	44%	8%	-58%	127%	-13%	-14%	-57%	55%	-21%	-16%
Netherlands	33%	44%	35%	7%	0%	8%	-17%	-4%	-1%	-14%	-12%	8%
Portugal	70%	44%	42%	8%	-22%	-19%	-13%	-34%	-50%	-39%	-22%	-35%
Romania	82%	21%	28%	-29%	-64%	-24%	-20%	-21%	-85%	-40%	-43%	-18%
Slovakia	36%	28%	31%	-5%	-38%	-27%	-56%	-20%	-26%	-40%	-56%	-18%
Slovenia	77%	41%	44%	-3%	-1%	15%	-13%	4%	-16%	-22%	-25%	3%
Spain [1]	69%	36%	25%	6%	-35%	37%	22%	2%	-42%	1%	25%	4%
Sweden	10%	31%	49%	7%	-35%	23%	-35%	-10%	-38%	6%	-49%	-11%
United Kingdom	76%	54%	39%	17%	-27%	2%	-23%	-9%	-56%	-28%	-30%	-10%
Norway	4%	19%	76%	14%	16%	30%	-29%	-9%	19%	17%	-53%	-10%
Switzerland	10%	46%	45%	20%	-29%	-16%	-28%	-28%	-30%	-38%	-39%	-35%
total ratifications	63%	42%	42%	10%	-39%	7%	-14%%	-16%%	-56%%	-20%	-24%	-16%
Austria	41%	36%	38%	1%	-46%	61%	-14%	-13%	-49%	21%	-28	-10%
Belgium	51%	43%	43%	8%	-8%	43%	-2%	8%	-19%	11%	-11%	4%
Greece	80%	41%	52%	14%	-68%	-32%	-34%	-33%	-82%	-44%	-47%	-36%
Ireland	72%	44%	40%	22%	-17%	54%	4%	-9%	-13%	13%	-6%	-15%
Italy	54%	43%	53%	9%	-32%	7%	-25%	-6%	-31%	-23%	-39%	-8%
Poland	43%	49%	45%	1%	-17%	-22%	-50%	-33%	-39%	-51%	-60%	-33%
Croatia	42%	40%	59%	-14%	-4%	-16%	-18%	0%	-11%	-39%	-53%	8%
Rep. of Moldova	11%	3%	-10%	-23%	-14%	-28%	-60%	8%	-25%	-30%	-59%	8%
total other signatories	51%	43%	49%	7%	-29%	-3%	-32%	-17%	-43%	-31%	-44%	-18%
Estonia	47%	39%	45%	-12%	-24%	-38%	-43%	-65%	-52%	-60%	-56%	-64%
Malta	78%	24%	57%	-58%	5%	-3%	-70%	-15%	-16%	-19%	-73%	-10%
Albania	3%	-66%	-29%	-17%	-46%	-22%	-7%	-25%	-43%	0%	4%	-24%
Belarus	-14%	-24%	-7%	-13%	-64%	-15%	-21%	-20%	-62%	-6%	-18%	-17%
Bosnia-Herzegovina	9%	-9%	-29%	-3%	-1%	-10%	-7%	-22%	-8%	-4%	6%	-20%
Russia [1]	-30%	-27%	-18%	5%	21%	13%	19%	-43%	33%	24%	21%	-41%
Serbia + Montenegro	58%	-4%	-11%	-9%	3%	10%	8%	-14%	-38%	14%	11%	-11%
TFYR of Macedonia	20%	-13%	-44%	0%	1%	40%	63%	-7%	-11%	50%	91%	-7%
Turkey	45%	11%	39%	-16%	-33%	-7%	1%	86%	-47%	-14%	-28%	104%
Ukraine	-65%	-56%	-87%	13%	-2%	1%	19%	-59%	28%	12%	50%	-57%
total other parties	-6%	-24%	-17%	-2%	-7%	5%	13%	-29%	-2%	12%	15%	-25%
Grand total all parties	35%	24%	26%	6%	-23%	4%	-8%	-20%	-30%	-10%	-15%	-19%

[1] *Only European territory*

the Protocol are unlikely to meet the 2010 targets without additional efforts. Some Parties have already formulated plans for additional abatement measures or indicated that they expect to meet the targets just one or two years later than 2010. But at least for three parties that have ratified, it seems difficult

Were assumptions on activity developments in the Gothenburg Protocol scenario correct?

How did changes in the activity projections affect the implementation of the Protocol? In general, increases in population, GDP and energy use developed in a very similar way as was assumed during the preparation of the Protocol. Current projections are in line with the scenario used for the Gothenburg Protocol. There are, however, a number of exceptions: in numerous countries (Bulgaria, France, Finland, Latvia, Norway, Sweden and Switzerland), consumption of fossil fuels is lower by more than 25 percent compared to what was assumed in the late 1990s, and coal use in many of the new EU Member States has declined substantially more than foreseen at that time. Ireland, Spain and Luxembourg experienced higher energy growth than earlier expected, often due to higher population and economic growth rates. Also, shipping (and associated emissions) is now higher than expected.

Many countries have indicated in their recent national scenarios that they expect an increase in the share of coal in power generation, as a consequence of the high oil and gas prices and the uncertainties in oil and gas imports. Also, many countries currently expect a further increase in the share of diesel oil in the transport sector, partly because of strong increases in freight transport that result from the enlargement of the EU. These assumptions would lead to higher emissions of SO_2, NO_x and PM.

At the time of writing this report, countries have not yet provided scenarios that take into account the ambitions expressed by the European Commission and the European Council to reduce, in 2020, greenhouse gas emissions by 20% and increase the share of renewables to 20%. Indicative calculations with the GAINS model show that implementation of these goals could result, as a side effect, in a reduction of NO_x emissions by 10-15% compared with the national projections. SO_2 emissions could even be 40-50% lower.

to achieve the targets even before 2020. Among others, lower effectiveness of the Euro-standards for vehicles and higher increases in activity levels than earlier expected seem to be the most important reasons. With current projections of activity levels, two parties would not meet the targets for SO_2 in 2020 without additional efforts, and two parties are expected to exceed the VOC ceilings. This analysis did not yet take into account the recent change in the ambitions of the EU-countries to reduce greenhouse gas emissions.

41. Emission projections that assume no further measures beyond what is already laid down in current legislation might be too pessimistic. Updates of projections received after 2006 have not been taken into account. This applies to Norway, but also to countries who have in the meantime developed more climate-compatible projections (UK, Germany, Poland, etc.). Information from the European Commission on the national plans submitted for the NEC Directive indicate that with envisaged additional measures all EU-27 countries are expected to meet their SO_2 ceiling under the NEC Directive in 2010. This Directive contains more stringent ceilings for some countries than the Gothenburg Protocol. For NO_x, six EU Member States indicated that they might not meet their ceiling. For three other Member States the situation is unclear since no plans were submitted. Two Member States might have difficulties meeting their ceilings. For VOC, two Member States might not meet their ceilings in 2010. All EU Member States are expected to meet their NH_3 ceilings, some of them with additional measures.

42. Also the projections for non-EU countries might be too pessimistic as, for instance, in the absence of confirmed legislation, no regulation for the emissions of new vehicles is assumed.

Costs

43. The implementation of the Gothenburg Protocol should lead to more cost-effective emission reductions than a flat-rate emission reduction agreement, an equal emission per head strategy or a 'level playing field' strategy aiming at equal emission limit values for industries across Europe. Nevertheless the Gothenburg Protocol could have been more cost-effective. There are two reasons. First, the Protocol is a little bit less cost-effective than the optimized scenario that was the starting point of the political negotiations, the so-called G5/2 scenario (see *Figure 8*). The negotiated ceilings of the Protocol deviate up to 10-20% from the results that have emerged from the cost-optimization analysis. Second: the cost-curves used in RAINS did not take into account the potential for structural changes in the energy sector, the traffic sector and in agriculture, as well as the potential for non-technical and local measures.

44. For 2010, total costs of emission control measures have been estimated at € 70 billon including the estimated € 7 billion incremental costs of the additional requirements of the protocol. Benefits of the Protocol were estimated at € 120-130 billion (when health benefits were valued according to the valuation of life years lost)[12]. Analysis for the EU27 has shown that the costs of meeting the same environmental improvements can be lower when additional abatement measures are taken for ships, and potential emission reductions in non-EU countries are taken into account, and when additional measures are taken to reduce greenhouse gas emissions.

Evaluation

45. Some Parties seem to face difficulties to meet the emission ceilings of the Protocol, while other Parties will substantially overachieve the ceilings with their current legislation. Especially for SO_2, the emission ceilings for the majority of the Parties seem to be more than 30% higher than the projected emissions, essentially because coal use turned out to be lower than expected.

46. Especially for those countries that, in the 1990s, transformed from centrally planned to market economies, the economic projections that have been used as the basis for the cost-effectiveness analysis for the Protocol underestimated the far reaching structural changes that have emerged since then. As a consequence, most of the Parties have already lowered their emissions below the Gothenburg ceilings in the period 2000-2005. This trend was enhanced by the environmental legislation that had to be adopted in the course of the accession to the European Union.

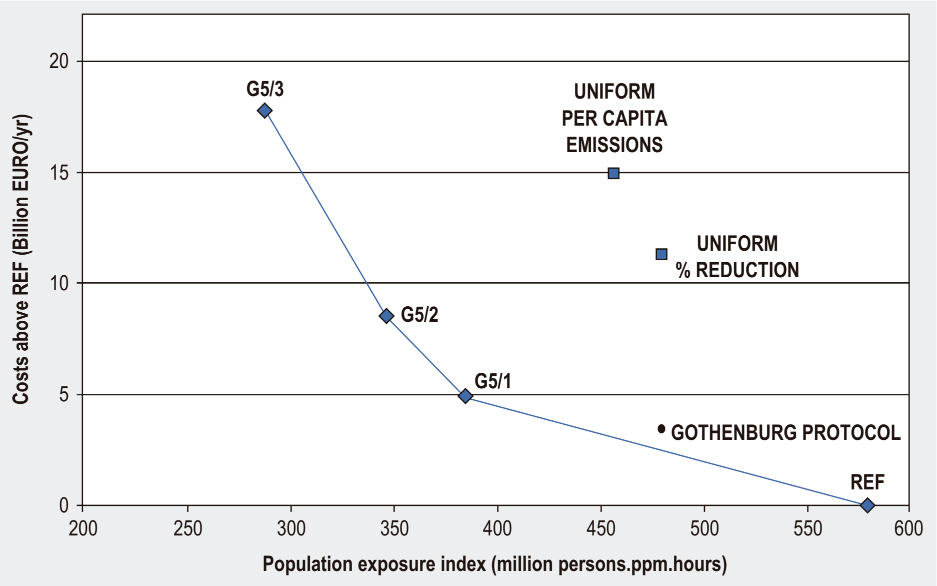


Figure 8: The Gothenburg Protocol is not the most cost-effective solution, but considerably more cost effective than if the Protocol would have been based on uniform emission reductions or on equal per capita emissions (Source:IIASA)

12 Holland, M., D. Forster, K. King, Cost-Benefit Analysis for the Protocol to Abate Acidification, Eutrophication and Ground level Ozone in Europe, AEA technology, 1999, VROM-publicatiereeks lucht & energie nr 133

V EMISSION LIMIT VALUES

Evaluation of technical annexes

47. The Expert Group on Techno-economic Issues evaluated the limit values in annexes IV, V and VIII of the Protocol. It also drew attention to the need to amend these annexes to the Protocol and its associated guidance documents.

48. The Expert Group noted that emission limit values (ELVs) for SO_2 and NO_x for large combustion plants (LCP) in annexes IV and V were partially different from those established by EU directive 2001/80/EC. The Expert Group also noted that relevant information on best available techniques (BAT) could be found in the Integrated Pollution Prevention and Control (IPPC) BAT reference (BREF) document for LCP (directive 96/61/EC). It suggested that this document could also be used for the assessment of ELVs for LCP installations and fuels which are not yet covered by the annexes (e.g. gas turbine installations, biomass).

49. Concerning heavy-duty vehicles and annex VIII to the Protocol, the Expert Group drew attention to the preparatory work in progress on Euro VI standards and noted that a proposed EU directive or regulation was expected in 2007. The development and implementation of this new EU legislation on Euro VI should be followed closely and, if appropriate, reflected in a revised annex VIII. For stationary engines, Parties may wish to consider the need to revise ELVs with regard to state-of-the-art engines and reduction techniques.

50. Also in annex VIII to the Protocol, sulphur content limit values are defined as 350 mg/kg for compression-ignition and 50 mg/kg for positive-ignition engines. These values could be revised downwards since Parties that are EU Member States already follow directive 1998/70/EC, which since 1 January 2005 has limited petrol and diesel fuels to a maximum of 50 mg/kg. Furthermore, EU directive 2003/17/EC amending directive 1998/70/EC, restricts from 1 January 2009 the sulphur content of petrol and diesel fuels further to 10 mg/kg.

51. Further consideration of revisions to annexes may now be appropriate. For example, the Expert Group has compiled removal efficiencies and abatement costs for some activities (refineries and cement), which might help with decisions on amendments. As only a limited number of activities are covered in the Protocol, Parties may wish to consider the need for adding others with significant emissions. Parties may also wish to consider reflecting other national or international legislation – for example, revising annex VIII for off-road engines to reflect EU directive 2003/44/EC for recreational craft and directive 2002/88/EC for emissions from internal combustion engines installed in non-road mobile machinery.

52. Some Parties have drawn particular attention to annexes that should receive immediate attention. For example, table IV of annex V, which lists limit values for NO_x emissions for new stationary engines, has created difficulties for several countries in their ratification process. Finland has offered to begin work on proposing revisions to table IV that would apply the same ELVs to all engines, from small unit spark ignition engines and compression engines up to large engine plants.

53. Parties may also wish to give special attention to the problems of the level of detail of the technical annexes. Some Parties to the Convention have indicated that, while they are able to meet the overall emission ceilings specified in annex II, they are having trouble ratifying the Protocol because of the stringent requirements of some of the annexes. Some delegations have suggested that a two-tier approach may encourage better implementation of the Protocol.

Uncertainties in emissions from vehicles

54. After the Protocol was agreed, considerable deviations were revealed between the expected vehicle emissions and the real life emissions. First this phenomenon was shown for heavy-duty vehicles and then later also for Euro-2 and Euro-3 diesel vehicles. As a result, NO_x emissions are now higher than expected in 1999. This phenomenon is one of the reasons that several countries have problems in meeting the national emission ceiling for NO_x.

Integrated nitrogen management

The Protocol has addressed emission reduction options for ammonia without taking into account the possible linkages with measures to abate nitrates in groundwater. This could lead to a less cost-effective policy strategy and to swapping problems between terrestrial and water ecosystems. Measures that reduce both nitrate and NH_3, such as producing fodder with low N content and more balanced fertilizing, were not given much attention. Analyses by the Dutch research institute Alterra shows that water quality policy could have a significant impact on intensive farming and on the emissions of NH_3. Full implementation of the Nitrate Directive of the EU could reduce emissions of NH_3 by an additional 10% as compared to the emission level reached with current legislation for NH_3 only. The Task Force on Integrated Assessment Modelling will organize a workshop on integrated assessment modelling of nitrogen in November 2007, together with members of the COST 729 project of the EU.

VI SYNERGIES WITH CLIMATE POLICY

Climate change and air pollution

55. There are close links between air pollution and climate change. The main sources of air pollutants and greenhouse gases are the same: combustion processes, transport and agriculture. Several abatement measures affect both air pollutants as well as greenhouse gases. Some measures (such as energy saving) reduce both types of emissions. Other measures reduce the emission of one gas while increasing the other emissions. The use of biomass for domestic heating, for instance, would reduce CO_2 emissions, but could increase the emissions of NO_x and particulate matter. Climate change will also affect atmospheric transport and air chemistry, e.g. increasing temperatures and dry conditions. Climate change could thus result in changes in source-receptor relationships for air pollutants. Climate change will also change precipitation patterns with could alter critical loads and the sensitivity of vegetation to air pollution. On the other hand, air pollution could also have an influence on climate change. Some air pollutants (such as sulphates) have a cooling effect; others (such as ozone and black carbon) contribute to temperature increases. Climate change increases transport of black carbon into the Arctic, which affects the albedo of the earth. Air pollution could cause changes in regional precipitation patterns. The ecosystem effects of air pollution could also contribute to changes in the carbon cycle: ozone damage will reduce carbon sequestration, because higher nitrogen deposition levels (in N-limited ecosystems) will stimulate carbon uptake.

56. With the exception of the decline in energy use resulting from the economic restructuring in Central and Eastern European countries, the consumption of fossil fuels, and as a consequence emissions of CO_2, are still rising in Europe. Compliance with the Kyoto Protocol obligations is largely being established through the accounting of the emission cuts in the new EU Member States that have occurred in the 1990s, the mitigation of non-CO_2 emissions and the implementation of CO_2 reductions abroad, which are accounted for with flexible mechanisms, such as joint implementation, clean development mechanism (see *Table 3*). However, the amounts and mix of fuels consumed will affect the end-of-pipe measures needed to reduce emissions of SO_2, NO_x, PM and VOC.

57. Since 2003, the RAINS model has been extended (with financial support provided by the Netherlands) to capture interactions between the control of conventional air pollutants and greenhouse gases (see *Figure* 9). This GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model includes, in addition to the air pollutants covered in RAINS, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the F-gases[13]. So the traditional RAINS model constitutes the air pollution-related part of the GAINS model, while the GAINS extensions address the interactions between air pollutants and greenhouse gases.

58. The GAINS model includes about 1500 abatement options for air pollutants and greenhouse gases. Each measure can impact several pollutants but has only one cost. In the optimization mode, the model determines how different environmental targets can be met at the same time against least costs. The model selects which measures belong to such a cost-effective solution. If GAINS is run in the RAINS-mode, only add-on abatement measures for SO_2, NO_x, NH_3, VOC and $PM_{2.5}$ are selected. When GAINS is run in the full mode, structural changes can also be selected: changes in activity levels, e.g. due to energy saving, changes in the fuel mix of power plants and introduction of renewable energy. For air pollutants, GAINS in the full mode will result in larger abatement potential and significant lower costs (see *Figure 10*). Reduction of air pollution costs appears to be an important co-benefit of climate change policy.

13 Klaassen, G., Amann, M., Berglund, C., Cofala, J., Höglund-Isaksson, L., Heyes, C., Mechler, R., Tohka, A., Schöpp, W., Winiwarter, W. (2004) The Extension of the RAINS Model to Greenhouse Gases. interim report, IIASA IR-04-015.

Table 3: CO_2 emissions by country, for the UNFCCC base year 1990, for 2000 and for 2020 for the national projections[14], and EU scenario with -20% CO_2 for the EU27 (PRIMES-coherent scenario)

	UNFCCC base year		**National projection**		**EU27 ambition (PRIMES)**	
	1990	**2000**	**2020**		**2020**	
	Mt	**Mt**	**Mt**	**Change to base year**	**Mt**	**Change to base year**
Austria	61	65	77	27%	66	8%
Belgium	119	126	131	10%	107	-10%
Bulgaria	98	46	48	-51%	33	-66%
Croatia	23	23	27	19%	21	-10%
Cyprus	5	7	9	73%	9	71%
Czech Republic	164	126	123	-25%	78	-53%
Denmark	53	53	54	2%	42	-21%
Estonia	38	19	27	-29%	10	-73%
Finland	56	58	59	5%	50	-11
France	397	414	462	16%	343	-14%
Germany	1015	860	854	-16%	669	-34%
Greece	84	104	93	11%	89	6%
Hungary	85	59	69	-19%	52	-39%
Ireland	32	45	59	84%	40	23%
Italy	431	472	503	17%	402	-7%
Latvia	19	7	17	-8%	8	-57%
Lithuania	39	14	28	-27%	16	-59%
Luxembourg	12	9	11	-5%	11	-11%
Malta	2	2	3	48%	3	32%
Netherlands	158	169	203	29%	159	1%
Norway	34	38	44	29%	37	10%
Poland	477	315	350	-27%	266	-44%
Portugal	44	66	80	83%	57	31%
Romania	184	92	143	-22%	95	-48%
Slovak Republic	59	39	60	2%	47	-20%
Slovenia	16	15	17	7%	15	-7%
Spain	228	306	451	98%	283	24%
Sweden	56	53	58	3%	55	-3%
Switzerland	45	43	42	-7%	39	-13%
Turkey	126	223	389	208%	273	116%
United Kingdom	589	559	536	-9%	433	-26%
Total	4749	4427	**5029**	**6%**	**3806**	**-20%**
Albania			7		6	
Belarus			67		43	
Bosnia & Herzegovina			22		11	
Macedonia			11		7	
Republic of Moldova			22		13	
Russia			1056		571	
Serbia + Montenegro			62		28	
Ukraine			441		301	
Total non Annex-1			**1689**		**979**	

59. With a EU policy aimed at 20% CO_2 reduction, the costs of additional measures, as envisaged under the EU-Thematic Strategy for Air Pollution, will decrease from € 7 billion to € 2 billion. Moreover, costs of current legislation will decrease from € 75 billion to € 65 billion (see *Figure* 11). With full implementation of the Kyoto obligations within the EU territory, the total costs of climate policy and air pollution policy are comparable to the costs of air pollution policy assuming increasing CO_2 emissions as envisaged in national projections.

60. Structural changes in energy, transport and agriculture aimed at greenhouse gas control have ancillary benefits for air pollution: less combustible fuels means additional reductions of emissions of SO_2, NO_x and PM, which means less health damage and less acidification of ecosystems; less CH_4 emission means

14 When no national energy projection has been submitted, data from the PRIMES €20 scenario are used instead

	PM	SO_2	NO_x	VOC	NH_3	CO_2	CH_4	N_2O	CFCs HFCs SF_6
Health impacts:									
PM	✓	✓	✓	✓	✓				
O_3			✓	✓			✓		
Vegetation damage:									
O_3			✓	✓			✓		
Acidification		✓	✓		✓				
Eutrophication			✓		✓				
Radiative forcing :									
– direct						✓	✓	✓	✓
– via aerosols	✓	✓	✓	✓	✓				
– via OH			✓	✓			✓		

Figure 9: The GAINS multi-pollutant/multi-effect framework (the RAINS framework is shown in blue)

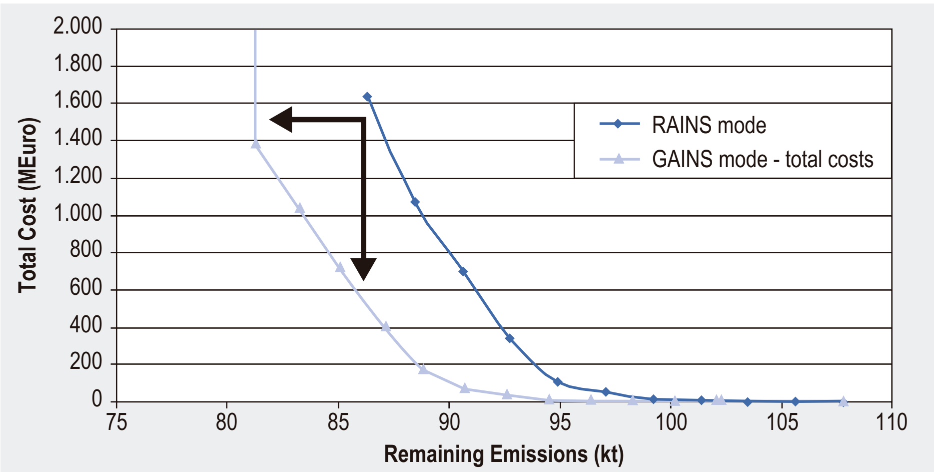


Figure 10: PM2.5 cost curve: two modes of GAINS. The GAINS-mode will lead to an additional abatement potential compared to RAINS, and to significant lower costs (Source: IIASA)

less ozone formation, less health impacts from ozone and less damage to crops and vegetation. These ancillary benefits will occur more locally and at a shorter term than the benefits of CO_2 control.

61. Energy efficiency and demand side management are clear synergy areas. Appropriate technology is available, but changes in consumption patterns and lifestyle changes must be taken into account in a joint strategy to control air pollution and climate change. Because it is difficult to quantify their implications reliably, a number of behavioural changes are not yet incorporated in GAINS. With the traditional methodology for cost calculation, the costs of measures like more bicycling, wearing a pullover or eating less meat could be negative, although experience shows that they are not adopted autonomously without additional (economic) instruments.

62. Emission trading of CO_2 and the use of flexible instruments such as joint implementation and use of the Clean Development Mechanism will shift the co-benefits of greenhouse gas mitigation to other regions. It is recommended that each country analyzes the total costs of climate policy and air pollution for various options of emission trading and optimizes the share of CO_2 emission reductions outside the country accordingly.

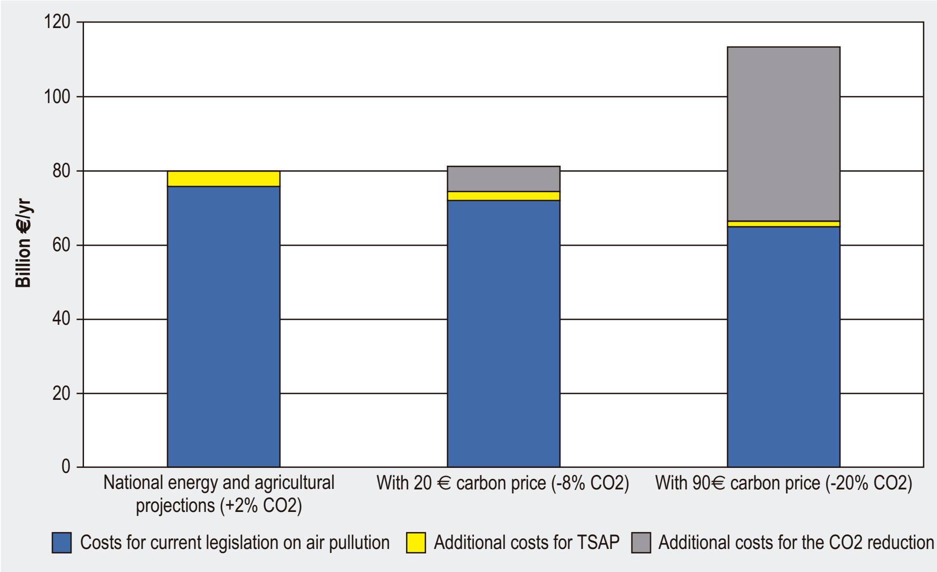


Figure 11: Climate policy will decrease the costs of air pollution policy (source: IIASA).

63. Not all measures aimed at mitigation of climate change will have these co-benefits. Some climate measures might increase emissions of air pollutants. The use of biomass in the heat, electricity and transport sectors could increase emissions of NO_x and $PM_{2.5}$, not only from direct biomass use, but also during production, transport and refinery of biomass. Depending on the type of biofuel, the life-cycle effects for air pollutants might substantial. Co-benefits, on the other hand, can be expected for NH_3, e.g. the use of manure for the production of biogas. The net radiative forcing effect of bio-fuels should also be analyzed further. A substantial increase in the use of biomass will increase the demand for land (for agriculture and forestry) and could thus increase food prices and loss of nature areas. It could also alter the albedo of the earth via changes in land use.

64. Agriculture is the dominant source of anthropogenic emissions of NH_3, CH_4 and N_2O. Some mitigation options (such as changes in cattle feed or reduction in the use of fertilizer) will reduce all three pollutants, but some NH_3 control measures would increase emissions of greenhouse gasses (e.g. injection of manure and low emission housing increases N_2O emissions and covered storage of slurry will increase CH_4 emissions).

65. Model studies indicate that climate change influences ecosystem processes and long-term impacts of air pollutants. The chemical and biological effects on biogeochemical cycles are complex and may affect acidification and eutrophication due to sulphur and nitrogen deposition. Climate change also affects nitrogen retention and organic acid leaching from soils, which are key processes and might lead to delays in recovery from acidification. Climate change affects plant physiology and development by reducing ozone flux uptake. The exceedance of flux-based critical levels for vegetation might be reduced across most regions of Europe in a future climate. Ambient ozone concentrations would increase through reduced uptake and result in enhanced radiative forcing, whilst ozone-induced productivity losses would continue and affect the global carbon cycle by reduced sequestration.

Research questions

66. During a workshop on air pollution and its relations to climate change and sustainable development (12-14 March in Gothenburg)[15] a number of questions were identified that were related to the interactions between climate change and air quality and that could currently not be answered sufficiently. Climate change could increase natural emissions (e.g. sea salt, and biogenic volatile organic carbon emissions). It might also alter removal rates of chemicals and the oxidizing capacity of the atmosphere. However, the magnitude of such influences is, as yet, unclear. Some models indicate that ozone could increase during the coming decades because of climate change. Detrimental ozone effects could become more persistent throughout the Northern Hemisphere for crops and semi-natural vegetation. While crop breeding programmes might moderate yield effects for crops, effects on reducing the carbon sink of semi-natural vegetation, especially forests, could prove to be an important factor.

67. Links between climate change and nitrogen are complex: NO_x influences air chemistry and decreases the lifetime of CH_4 and hydro fluoro compounds (HFCs), which can cause a cooling effect. But it also increases ozone, which is a greenhouse gas. Nitrogen deposition will increase carbon sequestration in vegetation and NO/N_2O emissions in N-limited ecosystems. Further research is required to quantify such effects. Also the role of land use interactions with climate and biogeochemical cycles are not yet fully understood (water use, energy crops). Land use changes, air pollution and climate change all modify CH_4 release from wetlands and VOC emissions from vegetation.

Policy recommendations

68. Air quality and climate change are seldom considered jointly. Separate policy developments for air quality and climate change strategies might fail to spot trade-offs early enough. Assessment of benefits would be incomplete (because co-benefits are ignored). Costs might be double counted. The assessment of the mitigation potential might be incomplete. And the best overall option might be overlooked while focusing on only one of the issues. Assessments and design of policy strategies therefore need to be brought together, costs need to be estimated jointly and potential synergies need to be explored and trade offs identified. For example, the air pollution implications of biofuels and carbon capture need to be looked into.

69. Not only the relationships between climate change and air pollution are important. Both issues are linked with other political topics: energy security, competitiveness, public health, etc. The linkages are not always obvious. Some may help, others may hinder attainment of environmental goals, but they cannot be ignored. Awareness of these relationships and more dialogue with policy makers that focus on economic or social issues might improve the effectiveness of future environmental policies.

15 report ECE/EB.AIR/WG.5/2007/9

VII CONCLUSIONS: PROGRESS TOWARDS ACHIEVING THE OBJECTIVE OF THE PROTOCOL

Sufficiency

70. Overall, the Gothenburg Protocol is likely to deliver its original goals in terms of emission reductions and closure of the gap between the 1990 deposition levels and the critical loads (see *Tables 4-6*). However, according to new scientific findings the exceedances of critical loads in the base year are higher than previously thought. Current legislation will not be sufficient to achieve the ultimate objective of the Convention, i.e. to bring deposition below critical loads and levels. With the implementation of the obligations under annex II of the Gothenburg Protocol, problems like acidification, eutrophication and health damage due to ozone and (secondary) particles will not be solved.

Effectiveness

71. Emissions have decreased in the last decades, most notably emissions of SO_2. Exceedances of the critical loads for acidification have declined. There are signs of chemical and biological recovery of acidified lakes. In contrast, exceedances of the critical loads for nitrogen have fallen only slightly, and positive impacts on biodiversity cannot yet be detected. There has been no significant change in ozone levels. Improved scientific understanding and a number of technical and methodological refinements lead to the conclusion that health and ecosystem risks from air pollution are higher than previously thought. The costs of attaining the emission targets could prove to be lower than expected.

Ratifications

72. To increase the effectiveness of the Protocol additional ratifications are needed. It is recommended to learn from the reasons for not ratifying. Some Parties have referred to the changing priorities in society as obstacles for ratification. Today, political stability, energy security, innovation and the future of agricultural subsidies, differences in tax structures are important issues in European policy. Within the environmental domain, climate change and - to a lesser extent - biodiversity loss receive relatively more political attention. To increase the political willingness for additional ratifications, the links between air pollution control and these other policy fields need to be highlighted. Other Parties have referred to unclear procedures on how to deal with new findings on base year emission inventories in the annex II obligations of the Protocol. Also the level of detail and inflexibility of the technical annexes IV-VI, and conflicts with newer insights into best available techniques were mentioned as reasons for non-ratification. Some Parties found it difficult to meet just one of the emission targets and therefore did not ratify the entire Protocol. A revised protocol might take these findings into account.

Towards achieving the long-term objectives

73. In order to meet the environmental long-term targets of the Protocol, a revision of the Protocol obligations should be considered. There exists a large potential for further cost-effective emission control measures, especially when their positive impacts on greenhouse gases are also considered. New emerging technologies, non-technical and local measures, integrated nitrogen management and reduction of ship emissions offer cost-effective options to reduce emissions further. *Figure 13* shows the environmental improvements that are possible with applying all technical feasible abatement options. Note that in these

Table 4: Development in environmental target indicators between 2000 and 2020 on the basis of current legislation calculated by GAINS (source: IIASA)

Country	**Loss in life expectancy due to PM 2.5 (in months)**		**Premature Deaths due to ozone per 1000 people older than 30**		**Ecosystems not protected for eutrophication (%)**		**Ecosystems not protected for acidification (%)**	
	2000	**2020**	**2000**	**2020**	**2000**	**2020**	**2000**	**2020**
Albania	5.4	3.8			100%	100%	0%	0%
Austria	7.8	5.0	92	56	100%	84%	1%	0%
Belarus	6.3	6.4			54%	52%	57%	52%
Belgium	12.2	8.5	81	52	94%	90%	70%	23%
Bosnia-Herzegovina	6.3	4.5			100%	100%	52%	25%
Bulgaria	8.2	5.6	114	95	94%	90%	0%	0%
Croatia	8.5	5.7	125	87	44%	40%	6%	0%
Cyprus	4.4	3.1	78	48	73%	76%	0%	0%
Czech Republic	9.6	6.3	112	63	100%	97%	82%	44%
Denmark	6.6	4.8	67	47	97%	81%	39%	3%
Estonia	4.8	4.6	31	26	55%	38%	0%	0%
Finland	3.0	2.8	19	15	47%	38%	2%	1%
France	7.6	4.5	82	52	98%	94%	13%	8%
Germany	9.3	6.3	86	56	98%	93%	61%	31%
Greece	7.7	4.7	98	68	100%	100%	10%	3%
Hungary	11.0	7.8	144	93	99%	80%	0%	0%
Ireland	3.8	2.3	50	28	83%	70%	22%	7%
Italy	8.1	5.2	132	87	70%	56%	0%	0%
Latvia	5.9	5.2	42	35	99%	95%	2%	0%
Lithuania	5.7	5.2	44	36	100%	100%	75%	59%
Luxembourg	9.2	5.9	152	81	100%	100%	38%	25%
Macedonia	5.8	3.9			100%	100%	33%	0%
Malta	6.1	5.0	132	72				
Republic of Moldova	8.3	7.7			0%	0%	3%	3%
Netherlands	11.5	8.2	53	33	93%	86%	84%	80%
Norway	2.5	1.8	37	27	4%	1%	18%	11%
Poland	10.0	7.3	80	47	98%	95%	60%	31%
Portugal	5.8	3.4	96	65	95%	93%	16%	5%
Romania	8.9	7.1	101	76	96%	96%	6%	1%
Serbia and Montenegro	7.5	5.3			100%	97%	33%	5%
Slovak Republic	9.4	6.7	105	57	99%	95%	24%	11%
Slovenia	8.4	5.6	111	60	100%	98%	11%	0%
Spain	4.8	2.8	84	52	88%	78%	1%	0%
Sweden	3.4	2.7	40	29	27%	10%	18%	9%
Switzerland	6.3	3.7	81	56	83%	54%	17%	6%
Ukraine	7.9	9.0			100%	100%	21%	20%
United Kingdom	6.7	4.2	60	43	28%	20%	33%	10%
Total	**7.9**	**5.5**	**81**	**55**	**60%**	**53%**	**20%**	**11%**

estimates the potential contribution from greenhouse gas abatement measures, from abating ship emissions and from an integrated nitrogen approach are not yet taken into account.

74. To enable a cost-effective outcome, a revised or new protocol should take into account linkages with primary PM emissions, hemispheric transport of air pollution and ship emissions, as well as the potential synergies and trade-offs to climate change policy and management of the nitrogen cycle.

75. The European Union has taken the initiative to formulate new ambition levels for its Member States for the period after 2010. The Thematic Strategy on Air Pollution defines ambition levels for 2020. Concrete measures to attain these targets are currently being explored for the revision of the NEC directive of the EU (see *Figure 12*).

Table 5: Projected emissions of SO_2 and NO_x based on national activity projections and current legislation compared with the national emission ceilings for 2010 and beyond (source: GAINS)[16]

	SO2					NOx				
	1990	**2000**	**2010**	**2020**	**Ceiling**	**1990**	**2000**	**2010**	**2020**	**Ceiling**
Bulgaria	1701	847	441	115	856	304	163	156	110	266
Cyprus	39	48	18	8	39	26	26	18	15	23
Czech Republic	1197	252	236	178	283	475	315	297	188	286
Denmark	96	28	19	21	55	247	213	168	126	127
Finland	188	76	66	59	116	272	212	169	129	170
France	1327	658	494	493	400	1854	1475	1187	867	860
Germany	5004	630	470	438	550	2930	1750	1212	933	1081
Hungary	969	484	144	67	550	223	186	140	106	198
Latvia	116	14	22	19	107	66	34	42	31	84
Lithuania	258	48	39	39	145	102	50	51	42	110
Luxembourg	23	4	2	2	4	20	33	25	17	11
Netherlands	182	75	50	50	50	549	410	287	230	266
Portugal	295	289	132	86	170	228	279	211	157	260
Romania	1366	773	331	139	918	527	329	334	261	437
Slovak Republic	547	128	68	81	110	156	109	95	79	130
Slovenia	183	99	27	23	27	71	60	52	35	45
Spain a/	2113	1457	501	446	774	1095	1343	1161	855	847
Sweden	131	46	43	41	67	306	229	182	157	148
United Kingdom	3614	1155	458	274	625	2925	1855	1204	845	1181
Norway	49	27	25	26	22	236	226	204	182	156
Switzerland	62	20	19	18	26	140	91	66	49	79
total ratifications	**19460**	**7158**	**3605**	**2622**	**5894**	**12752**	**9387**	**7260**	**5415**	**6765**
Austria	75	34	21	20	39	222	202	172	130	107
Belgium	380	175	98	86	106	400	351	259	201	181
Greece	447	483	175	96	546	325	326	233	192	344
Ireland	140	132	35	36	42	111	132	100	74	65
Italy	1791	755	340	345	500	2053	1353	1074	769	1000
Poland	3086	1509	1165	857	1397	1235	840	683	431	879
Croatia	172	108	67	62	70	87	87	73	53	87
Rep. of Moldova	197	114	117	102	135	88	64	64	63	90
total other signatories	**6287**	**3309**	**2018**	**1605**	**2835**	**4521**	**3355**	**2658**	**1912**	**2753**
Estonia	243	90	76	48	*100*	74	39	37	24	*60*
Malta	21	34	9	8	*9*	7	8	8	6	*8*
Albania	74	32	30	31	*55*	23	22	28	36	*36*
Belarus	851	159	173	182	*480*	378	193	217	239	*255*
Bosnia-Herzegovina	484	420	411	380	*415*	73	53	54	58	*60*
Russia a/	6103	2399	2842	3125	*2352*	4465	2592	3001	3297	*2653*
Serbia and Montenegro	593	397	277	168	*269*	220	166	168	173	*152*
TFYR of Macedonia	110	90	82	72	*81*	46	38	41	43	*29*
Turkey	1515	1646	1145	911	*1708*	693	822	795	731	*852*
Ukraine	3689	1134	1429	1866	*1457*	1739	873	1232	1363	*1222*
total other parties	**13683**	**6401**	**6474**	**6790**	*6926*	**7718**	**4807**	**5580**	**5970**	*5327*
Grand total all parties	**39430**	**16868**	**12097**	**11018**	**15655**	**24991**	**17550**	**15499**	**13297**	**1484**

76. The action plan for Eastern European, the Caucasus and Central Asian (EECCA) countries offers possibilities for transfer of knowledge and technologies to measure and model air pollution and to support air pollution policies in EECCA countries. Also, for Balkan countries means are available to support policy development, e.g. for bilateral consultations on improving the data used in GAINS. Meanwhile MSC-W is working on extending the geographical scale of the EMEP model, which would enable the integration of EECCA data in integrated assessment models.

16 For countries without a ceiling RAINS estimates for 2010 are presented in italics; these were made for the preparation of the Protocol. Ceilings lower than the projected emissions are marked. Note that meanwhile several EU Member States have produced additional reduction plans in order to meet the obligations

Table 6: Projected emissions of VOC and NH_3 based on national activity projections and current legislation compared with the national emission ceilings for 2010 and beyond (source: GAINS)[17]

	VOC					NH3				
	1990	**2000**	**2010**	**2020**	**Ceiling**	**1990**	**2000**	**2010**	**2020**	**Ceiling**
Bulgaria	203	134	133	86	185	134	69	67	68	108
Cyprus	16	14	6	5	*14*	6	7	7	7	9
Czech Republic	375	234	194	148	220	127	84	79	77	101
Denmark	197	141	92	71	85	96	91	58	53	69
Finland	205	160	111	91	130	40	35	31	30	31
France	2462	1803	949	862	1100	687	702	655	651	780
Germany	3051	1461	1039	858	995	712	601	471	448	550
Hungary	274	161	122	117	137	136	77	82	90	90
Latvia	92	69	58	43	136	44	13	14	15	44
Lithuania	106	69	53	42	92	80	37	37	40	84
Luxembourg	15	13	8	7	9	6	6	6	6	7
Netherlands	393	259	158	168	191	209	149	123	138	128
Portugal	299	270	175	157	202	71	76	71	70	108
Romania	534	414	417	298	523	260	133	165	173	210
Slovak Republic	124	88	62	61	140	54	31	31	32	39
Slovenia	57	53	35	30	40	26	20	21	21	20
Spain a/	1187	1125	815	838	669	335	390	360	368	353
Sweden	466	240	156	123	241	58	55	51	51	57
United Kingdom	2197	1380	920	837	1200	369	323	270	267	297
Norway	328	380	139	91	195	23	24	21	21	23
Switzerland	275	160	103	88	144	61	52	45	41	63
total ratifications	**12854**	**8627**	**5746**	**5022**	**6648**	**3531**	**2976**	**2666**	**2665**	**3171**
Austria	319	184	136	114	159	65	60	58	59	66
Belgium	340	225	141	128	144	85	84	80	77	74
Greece	366	291	171	139	261	66	54	49	47	73
Ireland	100	86	57	51	55	116	125	105	98	116
Italy	1842	1509	870	702	1159	428	425	395	385	419
Poland	805	578	400	319	800	376	317	314	312	468
Croatia	105	102	74	42	90	37	28	30	32	30
Rep. of Moldova	53	37	40	41	100	45	37	45	45	42
total other signatories	**3929**	**3013**	**1890**	**1537**	**2768**	**1219**	**1129**	**1075**	**1056**	**1288**
Estonia	56	39	28	22	*49*	23	9	10	11	*29*
Malta	7	7	4	3	*12*	2	2	3	3	*3*
Albania	36	33	38	43	*41*	24	23	26	27	*35*
Belarus	313	236	246	252	*309*	194	115	126	131	*158*
Bosnia-Herzegovina	48	39	45	51	*48*	23	18	18	18	*23*
Russia a/	3705	2856	3323	3363	*2786*	1200	551	509	524	*894*
Serbia and Montenegro	156	139	151	155	*139*	77	67	71	73	*82*
TFYR of Macedonia	21	25	31	36	*19*	15	15	15	15	*16*
Turkey	763	784	664	474	*656*	397	422	449	491	*241*
Ukraine	1034	640	946	1196	*797*	709	292	246	253	*592*
total other parties	**6138**	**4800**	**5475**	**5595**	***4856***	**2664**	**1514**	**1472**	**1545**	***2073***
Grand total all parties	**22921**	**16439**	**13111**	**12154**	**14272**	**7414**	**5619**	**5213**	**5266**	**6532**

Further work

77. The Task Force on Integrated Assessment Modelling will continue to assess progress in European-wide integrated assessment modelling, especially the GAINS model. Special attention will be paid to the inclusion of costs and effects of greenhouse gas abatement options, integrated nitrogen approaches and abatement measures for ship emissions. When the geographical coverage of the EMEP model is enlarged, the GAINS model will be able to include additional Parties to the Convention that lie outside the current EMEP domain. The treatment of uncertainties in projections and optimization results will also continue to play an important role. Improvements in the quality of critical load data, air quality measurements, emission data and emission projections are of great importance for the reliability of the results of integrated assessment models. It remains crucial to share experiences with national integrated assessment modelling activities.

17 For countries without a ceiling RAINS estimates for 2010 are presented in italics; these were made for the preparation of the Protocol. Ceilings lower than the projected emissions are marked. Note that meanwhile several EU Member States have produced additional reduction plans in order to meet the obligations

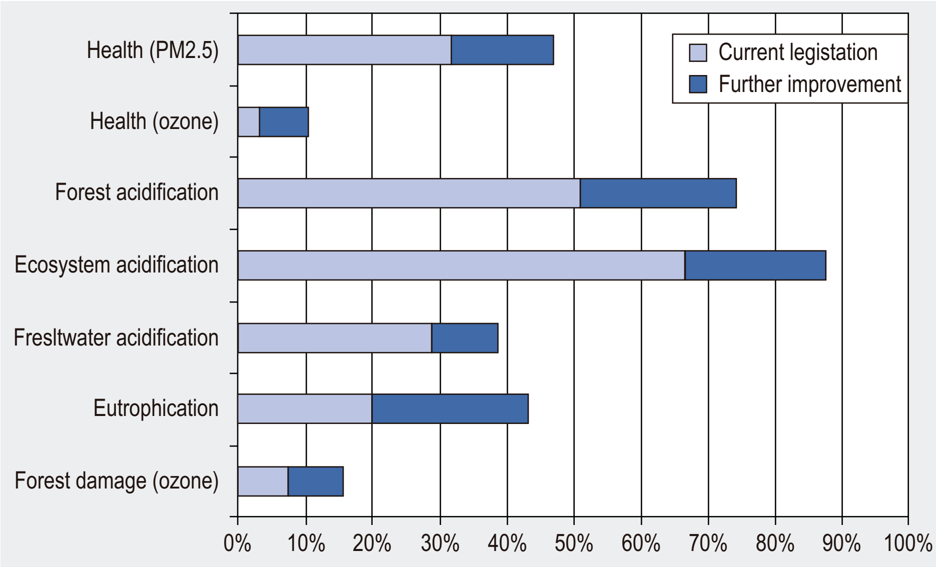


Figure 12: Environmental targets of the Thematic Strategy on Air Pollution of the European Commission. Reductions expressed as percentage improvements between 2000 and 2020.

78. Integrated assessment models will have to include new scientific findings that are expected in the coming years, e.g. better knowledge of the sources of particulate matter, as well as its chemical composition; improved insights in the complex interactions between air pollution and climate change; and new developments in ozone-flux modelling and the dynamic modelling of ecosystem effects of acidification and eutrophication.

79. Assessments of the potential contribution of emerging technologies and structural changes in the energy, transport and agricultural sectors would be important to obtain an indication of possible further progress towards the long-term objectives of the Protocol. For this purpose, the development of more explorative scenarios for the longer run (e.g. towards 2050) are being considered.

80. Concrete scenario activities by CIAM and the Task Force depend on the political choices that will be made regarding the inclusion of particulate matter in a revised or new protocol and the way the Convention would like to deal with the linkages with climate change policy, ship emissions policy and nitrogen policies (other than ammonia). Will a revised or new protocol be based on the current national projections (that exclude such policies)? Or on the policy ambitions currently expressed by the European Union for climate change, ship emissions and (ground) water pollution? Or will such ambitions be used for sensitivity analyses only? Such choices will have practical implications for the workplan and the timing of a revised or new protocol.

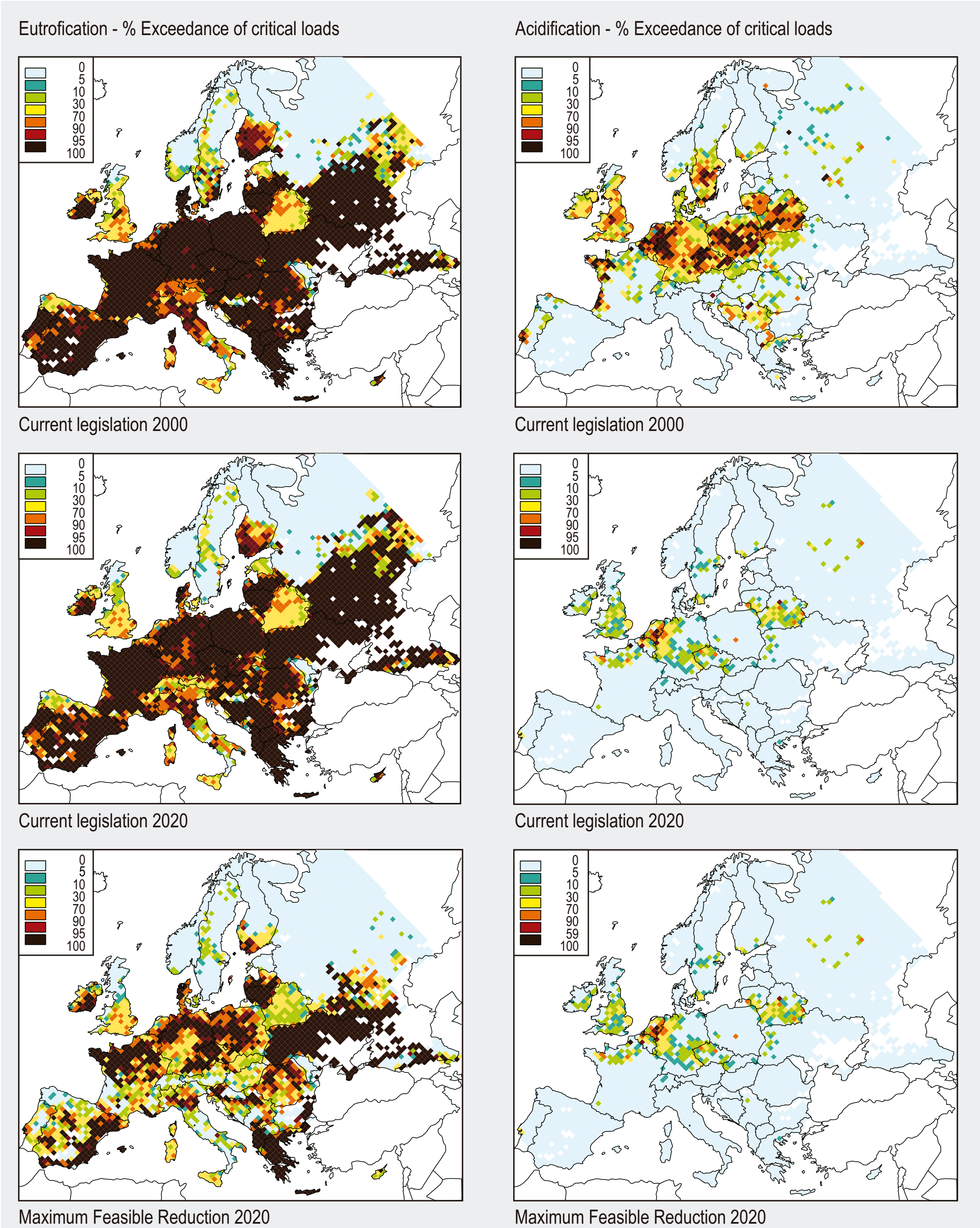


Figure 13: Potential environmental improvements between 2000 and 2020 with current legislation and maximum technically feasible abatement measures

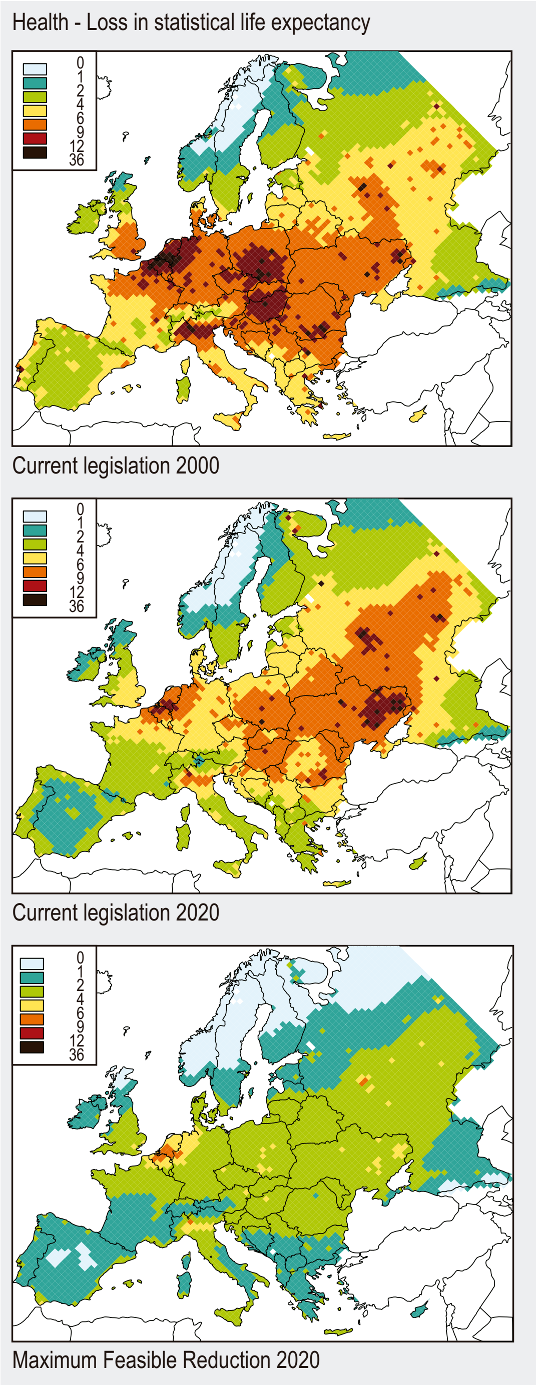


Figure 13ctd: Potential environmental improvements between 2000 and 2020 with current legislation and maximum technically feasible abatement measures

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ANNEX: STATUS OF RATIFICATION OF THE GOTHENBURG PROTOCOL MAY 2007

	1999 Multi-effect Protocol (i)		
	Signature	Ratification*	
Albania			
Armenia	01.12.1999		
Austria	01.12.1999		
Azerbaijan			
Belarus			
Belgium	4.2.2000 (1)		
Bosnia and Herzegovina			
Bulgaria	01.12.1999	05.07.2005	(R)
Canada	01.12.1999		
Croatia	01.12.1999		
Cyprus		11.04.2007	(Ac)
Czech Republic	01.12.1999	12.08.2004	(R)
Denmark	01.12.1999	11.06.2002	(Ap)(6)
Estonia			
Finland	01.12.1999	23.12.2003	(At)
France	01.12.1999	10.04.2007	(Ap)
Georgia			
Germany	01.12.1999	21.10.2004	(R)
Greece	1.03.2000		
Holy See			
Hungary	01.12.1999	13.11.2006	(Ap)
Iceland			
Ireland	01.12.1999		
Italy	01.12.1999		
Kazakhstan			
Kyrgyzstan			
Latvia	01.12.1999	25.05.2004	(At)
Liechtenstein	01.12.1999		
Lithuania		02.04.2004	(Ac)
Luxembourg	01.12.1999	07.08.2001	(R)
Malta			
Monaco			
Montenegro			
Netherlands	01.12.1999	05.02.2004	(At) (3)
Norway	01.12.1999	30.01.2002	(R)
Poland	30.05.2000		
Portugal	01.12.1999	16.02.2005	(Ap)
Republic of Moldova	23.05.2000		
Romania	01.12.1999	05.09.2003	(R)
Russian Federation			
San Marino			
Serbia			
Slovakia	01.12.1999	28.04.2005	(R)
Slovenia	01.12.1999	04.05.2004	(R)
Spain	01.12.1999	28.01.2005	(R)
Sweden	01.12.1999	28.03.2002	(R)
Switzerland	01.12.1999	14.09.2005	(R)
The FYR of Macedonia**			
Turkey			
Ukraine			

	1999 Multi-effect Protocol (i)		
	Signature	**Ratification***	
United Kingdom	01.12.1999	08.12.05	(R)
United States	01.12.1999	22.11.04	(At)
European Community		23.06.2003	(Ac)
Total:	31	23	

(i) Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, adopted 30.11.1999 in Gothenburg (Sweden), entry into force 17.05.05.

Notes:* R = Ratification, Ac = Accession, Ap = Approval, At = Acceptance, Sc = Succession

(1) With declaration upon signature.

(2) With declaration upon ratification.