Convention on Long-Range Transboundary Air Pollution

Assessment Report 2016

Draft 17 December 2015

EMEP Steering Body and Working Group on Effects

Rob Maas, Peringe Grennfelt (editors)

Contents

Document status

This document was prepared under the auspices of the EMEP Steering Body and the Working Group on Effects at the request of the Executive Body of the UNECE Convention on Long-Range Transboundary Air Pollution. The EMEP Steering Body and the Working Group on Effects cover the scientific network within the UNECE-region. This network was developed during the past 35 years in order to support effect-based cost-effective air pollution policies with the best available knowledge.

The Assessment Report summarizes the existing scientific knowledge and describes the effectiveness of air pollution measures in avoiding large scale effects to forests and lakes as well as in protecting human health and other air pollution effects, e.g. the loss of biodiversity and the damage to crops and materials.

The assessment of achievements is based upon an analysis of trends in air pollution and impacts, coordinated by the Working on Effects: Heleen A. de Wit, Jean-Paul Hettelingh, Harry Harmens (editors) Trends in ecosystem and health responses to long-range transported atmospheric pollutants, NIVA, 2015, ISBN 978-82-577-6582-8).

The assessment of opportunities to tackle remaining challenges is based upon work by the EMEP Task Force on Hemispheric Transport on Air Pollution, the Meteorological Synthesizing Centre-West, the Meteorological Synthesizing Centre-East, and the Centre on Integrated Assessment Modelling.

The goal of the report is to serve as a basis for considering new directions for policy development and the identification of additional policy relevant research questions. The international co-operative approach including the interaction between science and policy, as developed under the Convention, would form a good basis for exploring synergies between air pollution and climate change, agriculture and biodiversity, as well as energy and public health policies on the urban, national as well as long-range regional scale.

The current draft is made available to gather comments from experts from the different bodies under the convention. Experts are invited to send comments – as specific as possible – before 15 February 2016 to the editors of the report: rob.maas@rivm.nl and peringe.grennfelt@ivl.se. A final draft will be presented for approval to the bureaux of the EMEP Steering Body and the Working Group on Effects on 14 March 2016. The approved Assessment Report will be presented during the 35th session of the Executive Body of the Convention on 2-4 May 2016.

To do list

- Include texts on US/CAN (15 Febr)
- Add para on gaps in knowledge and data
- Check the consistency in the use of terms EU, Europe, Western Europe, UNECE-Europe, EMEP-region and clarify
- Include missing references

Main points

1. Without pollution abatement triggered by the CLRTAP protocols, acidification of soils and waters in 2010 would have been 30 times higher and three times more people would have died prematurely. According to current science fine particles, ozone, nitrogen, heavy metals and persistent organic pollutants are still causing health and ecosystem effects in the UNECE region.
2. More than 95% of the urban population in the EU is exposed to concentrations of fine particles (PM2.5) and ozone above the WHO guideline level. The current number of premature deaths associated with air pollution (nearly 600 000 within the entire UNECE region) is 10 times higher than the number of lethal traffic accidents. The costs of control are generally far less than the damage costs to health and environment. For industry the costs of absence from work due to air pollution only is higher than the cost of abatement measures.
3. International coordination of air pollution policy remains indispensable, as a substantial part of health and ecosystem impacts is caused by transboundary transport of pollutants. Effective reduction of the PM2.5 exposure of the urban population requires emission reductions of precursor emissions in a wider area: especially further reduction of ammonia is cost-effective.
4. While recovery of ecosystems from acidification is ongoing in some parts of Europe, excess deposition of nitrogen is currently a major cause of biodiversity in the EU. It stimulates dominant species such as grasses, bushes, algae and nettle. Reducing emissions of ammonia and nitrogen oxides is more cost effective than additional nature management to protect threatened species. There are many cost-effective ammonia measures within the agricultural sector, in particular for the largest 3% of livestock farms.
5. Current ozone concentrations reduce potential wood and crop production in Europe by up to 15%. Background concentrations of ozone, mercury and several persistent organic pollutants in Europe and North America are influenced significantly by emissions outside these continents. Reduction of background concentrations in the entire UNECE region would require scientific and policy collaboration across the Northern Hemisphere, e.g. in order to identify additional cost-effective abatement options of precursor emissions of ozone (including methane).
6. Climate policy and air pollution policy cannot be seen separately. Energy savings and shifts in the energy mix have contributed to cleaner air and will continue to be important in the coming decades. However, promoting the use of biomass and biofuels could increase air pollution. Emission reduction of black carbon (e.g. from diesel and inefficient stoves) and methane can limit the speed of temperature increase in the next decades.
7. The net impact of abatement measures on national income and employment will in many countries be neutral as production of the technologies required, also create employment.
8. Ratification and implementation of CLRTAP protocols could enable an international level playing field for industries and prevent countries competing with each other at the expense of environment and health.
9. Improvement of emission data and further harmonisation of monitoring air quality and health and ecosystem impacts can help to assess policy progress. Exploring potential synergies between air pollution policies at the local, regional and hemispheric scale, as well as with energy and agricultural policies could identify cost-effective additional measures.

Summary for policy makers

A world avoided

Without measures sulphur emissions in Europe would have more than doubled over the past 30 years. Technological solutions such as flue gas desulphurization and low-sulphur fuels were dominant measures. Catalytic converters in cars were applied to reduce NO_x-emissions. Its costs became lower as more countries applied these cleaner technologies. Environmental measures contributed to one-third of the decoupling between production and consumption growth and the development of emissions. Energy policy and general technological progress also played a significant role in decoupling production and consumption growth from the development of emissions: coal was substituted by gas and non-fossil energy and products and production processes became more energy efficient. Also in the future air pollution trends will be influenced by both environmental measures and energy policy.

If no decoupling of economic growth and air pollution trends would have occurred, the total exceedance of the critical loads for acidification in Europe would have been 30 times higher than the current exceedance. The total exceedance of the critical loads for nitrogen would have been 3 times higher. Average PM2.5 exposure would have reached levels that are currently measured in the Po-valley. Health impacts from PM-exposure would have been 3 times higher and 600.000 more people would have died prematurely. Compared to this hypothetical world avoided 12 months of average life expectancy has been gained. The health impacts from ozone would have been 70% higher and ozone damage to crops would have been 30% higher.

Nevertheless, according to current science, fine particles, ozone, nitrogen, heavy metals and persistent organic pollutants are still causing health and ecosystem effects in the UNECE region. *Air pollution causes damage to health and nature*

Air pollution is still the number one environmental cause of premature deaths in Europe. A persistently high number of people are exposed to harmful pollutants in outdoor air, such as particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2). Outdoor air pollution, particulate matter, one of its major components, and diesel engine exhaust have been classified as carcinogenic to humans by the International Agency for Research on Cancer. In 2014, the World Health Organization (WHO) published its latest estimates of the burden of disease related to ambient (outdoor) and household (indoor) air pollution. For 2012, 576,000 premature deaths were attributable to ambient air pollution and 118,500 premature deaths to household air pollution in the ECE region (including ECE member States in North America). The majority of these deaths were due to cardiovascular, cerebrovascular and respiratory diseases, as well as lung cancer.

The current number of premature deaths due to air pollution is 10 times higher than due to traffic accidents. The number of life years lost in Western Europe due to outdoor air pollution is twice as high as in North America (OECD, 2014).The number of life years lost in EECCA-countries (including West-Balkan) is 20% higher than in Western Europe (WHO, 2015). The average loss in life expectancy in Europe due to fine particles is estimated by IIASA to be about 5 months, but in several urban areas the loss of life expectancy is more than 12 months. In a recent public opinion survey air pollution was mentioned as the number one concern of the public (Eurobarometer, 2014).

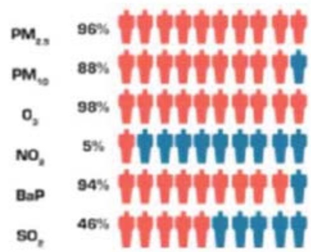


Figure 1: Share of the EU population living in areas above WHO air quality guideline levels (in red). More than 95% of the population is exposed to high levels of PM2.5 and ozone (O_3)

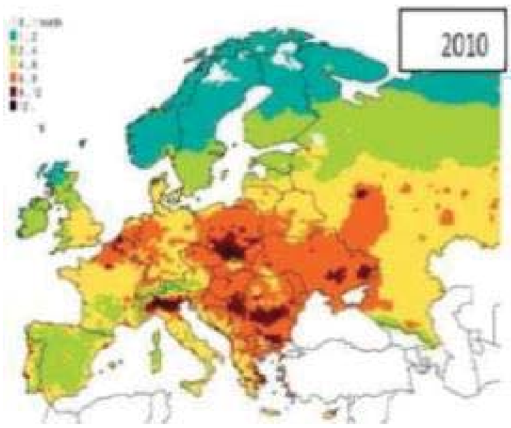


Figure 2: Average loss in life expectancy due to PM2.5 in months per person

Air pollution also causes damage to nature. Deposition of sulphur and nitrogen leads to acidification of soils and waters and ecosystems in large areas of Europe and eastern North America have been affected. The major reduction of emissions of sulphur dioxide (SO_2) since its peak around 1980 has reduced depositions. In some parts recovery of forests and lakes is ongoing, although in many parts the acidification is continuing be it at a much slower pace.

Excess deposition of ammonia (NH_3) and nitrogen oxides changes the vegetation and many protected species are displaced by dominant species such as grasses, bushes and nettle. This may have a knock-on effect on butterflies, other insects and birds. Excess nitrogen deposition could lead to an increase of plants and insects that cause allergies or diseases and contributes to algae bloom in water ecosystems together with other sources of nitrogen pollution.

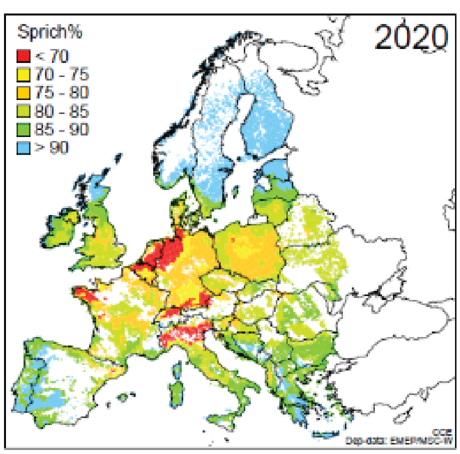


Figure 3: Estimated share of species in grasslands that may not be affected by European nitrogen deposition in 2020with the Revised Gothenburg Protocol (Adapted from: Hettelingh et al., 2015) Red colours show areas where less than 70% of the plant species in grassland will not be affected.

For the European UNECE region the total economic costs due to premature death are estimated at around €1 trillion (WHO, 2015). Costs of illness (e.g. hospitalisation and medicine use) due to air pollution are estimated to add 10% to this amount. In half of the UNECE countries the total health costs due to air pollution is more than 10% of GDP (WHO, 2015). Air pollution also has consequences for industry: it causes 5-10% of the absence from work due to sickness. For the EU28 it was estimated that the emission reductions proposed by the European Commission would lead to more cost-reductions for industry due to less sickness absence, than the costs of additional air pollution abatement measures (EC, Impact Assessment, 2013).

Up to 15% of the production of crops and wood in Europe is lost due to ground level ozone, depending on species sensitivity (source: ICP-Vegetation). The economic damage to wheat production alone in the European EMEP is already € 4.6 billion annually. Ozone could also affect future agricultural productivity due to decreased pollination.

The damage from air pollution to materials and cultural heritage in Europe is estimated to be more than € 2 billion per year (Source: ICP-Materials).

Heavy metals and persistent organic pollutants are known for their toxicity and have adverse effects on human health and the environment (carcinogenicity, mutagenicity, reproduction toxicity, endocrine disruption, etc.). Due to accumulation along food chains and in individuals even low environmental concentrations can lead to significant exposures over time.

Despite a decline in emission levels and the number of 'hot spots' close to industrial regions, long term risks for human health and the environment continue to exist in many UNECE countries. E.g. in a number of countries critical loads for mercury are still exceeded (Source: ICP Mapping and Modelling).

Air pollution is more than a local problem

In several European cities a significant part of the concentrations of fine particles is caused by long-range transport and consists of ammonium-nitrate and ammonium-sulfate (so-called secondary particles that are formed in the air out of emissions of ammonia, sulphur and nitrogen oxides). Moreover it has become clear that ozone concentrations are to a large extent influenced by transboundary and even transcontinental transport of its precursors: NO_x, volatile organic compounds (VOC) and methane. Local actions alone will for many cities not be sufficient to meet WHO guideline levels. National and international co-ordinated actions will continue to be indispensable for such a target. Ratification of the current CLRTAP-protocols will not be sufficient. Even actions beyond the current CLRTAP mandate will be needed that could require new policy fora or legal instruments.

Also for mercury and some persistent organic pollutants intercontinental transport is becoming an important issue. Many of the local hotspots have been tackled and the remaining challenge is to reduce the global background level. This global aspect has also been the reason for the foundation for the Stockholm Convention on Persistent Organic Pollutants and the Minamata Convention on Mercury.

Solutions are available

In the past much of the reduction of air pollution was the combined effect of end-of-pipe abatement measures and structural changes in the energy, transport and agricultural systems. Also in the future trends in air pollution will be closely related to developments in the use of fossil fuels and developments in transport and livestock. Future air quality could profit from climate and energy measures or an environmentally friendly agricultural policy. Sufficient technical measures are available to further reduce emissions from e.g. combustion installations, vehicles, ships and farms that would be needed to reach the WHO guideline levels[1] for fine particles and ozone in most places in Europe and to avoid excess nitrogen in most European nature areas. For heavy metals and persistent organic pollutants, a variety of measures are available and coordination with other conventions and policy frameworks can provide opportunities for solutions.

Benefits will exceed costs

The direct costs of additional measures as proposed by the European Commission for EU-countries will be less than 0.01% of the European GDP. Economic models show that some sectors will lose jobs (e.g. the fossil fuel sector); but that other sectors will gain jobs (e.g. the building and equipment sectors). The total impact on employment will be negligible. In the long run environmental policy will favour the economy as it stimulates more efficient use of resources (JRC, 2013, PBL, 2014).

Some economic benefits of additional abatement measures for health, e.g. less absence due to sickness, will be felt immediately.

With an international co-operative approach each country would also benefit from reduced transboundary pollution. A larger market for clean technologies will reduce the costs of producing the required equipment and thus the abatement measures. Countries that move first expand their possibilities for a growing clean tech industry.

Learning from the past: the acidification case

The current challenges for reducing health effects from fine particles are comparable to the acidification of lakes and forest soils that was revealed in the 1970s. This acidification problem was succesfully managed through an international co-operative approach addressing combustion sources and human and natural receptors simultaneously. This approach, that was triggered by acidification of lakes, forests and monuments, helped recognize that multiple combustion sources generated emissions of many compounds that acted simultaneously to cause effects on human and ecosystem health. For example, policy efforts to reduce ecosystem acidification through sulphur abatement turned out to also diminish the emission of particles, thus protecting human health. The reduction of nitrogen oxide emission from car exhaust also reduced the emissions of lead. In fact, nitrogen emission reduction from combustion sources, helped protect nature from acidification, eutrophication and ground-level ozone damage while diminishing the risk of lead deposition. Simultaneously, this policy contributed to human health protection by diminishing excessive exposure to particles, ground level-ozone and lead.

It turns out that the need for unleaded gasoline, generated by nitrogen abatement policies, helped to reduce lead pollution levels in the UNECE countries by almost 80% in the period 1990-2012, but not sufficiently to protect European nature everywhere (ICP Modelling and Mapping). The highest reduction rates took place in the beginning of the period, reaching 15-18% per year in a number of countries (e.g., Finland, Denmark, Germany, Spain, Norway etc.). This fast decline is explained by the rapid phasing out of leaded gasoline.

[1] Or comparable guideline levels in the US and Canada

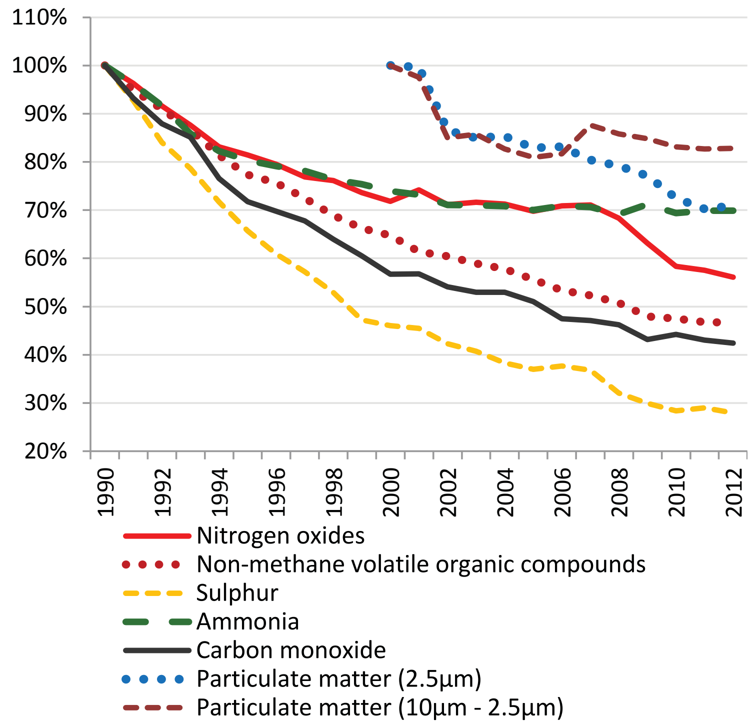


Figure 4: Emission trends in the ECE-region (excluding Canada and the United States of America), Emission of sulphur showed the steepest decline between 1990 and 2012 (Source: EMEP-Centre for Emission Inventories and Projections)

Air pollution as a global problem

Reductions of ozone precursors resulted in a reduction in peak ozone exposure since the 1990s. However the burden of disease from ozone is not restricted to exposure during occasional air pollution peaks, but also comes from longer-term exposure to ozone. Background concentrations of ozone in Europe don't show a significant downward trend. Concentrations in Europe and North America are for a substantial part the result of emissions in other parts of the Northern Hemisphere and reduction will require broader international co-ordination than the European or North American scale.

This is also the case for some persistent organic pollutants, e.g. HCB, dioxins and PCBs, and mercury, where measures within the CLRTAP-area will not be sufficient to significantly reduce concentrations. This is why the LRTAP Convention is promoting scientific collaboration on the Northern Hemispheric scale through its Task Force on Hemispheric Transport of Air Pollution.

Also the LRTAP Convention seeks to increase synergies and cooperation with other international conventions, programs and policies (e.g. the Stockholm Convention, the Minamata Convention and others, the Arctic Monitoring and Assessment Programme under the Arctic Council, and the regional sea conventions such as HELCOM and OSPAR).

Actions at different levels

The air pollution policy agenda is currently dominated by public health concerns both in cities and in international policy fora. Monetised health damage exceeds estimates for other damage categories (such as crops and materials). Damage to ecosystems comes in addition, but is difficult to monetise. Abatement costs are significantly lower than the benefits from reduced damage. Episodes with high levels of pollution raise public concern, cause health complaints and make air pollution literally visible. Several local initiatives are taken to develop ‘healthy’ cities. But cities cannot reduce the air pollution levels down to the WHO guideline levels on their own, since sources outside the cities often contribute significantly to local air pollution concentrations, and may sometimes even be the dominating factor. Local air pollution risks are still a transboundary phenomenon in many cities of Europe. A reduction of exposure to fine particles (PM2.5) to the recommended concentrations will not only require local reductions of emissions of primary particulate matter in cities (such as black carbon), but also of precursor emissions of secondary particles in a much wider area: sulphur dioxide, nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds (VOC).

In several cities in Europe a major part of the concentrations of fine particles consist of secondary particles that are formed in the atmosphere during air pollution transport and are the result of emissions in other cities as well as rural areas. Ammonia is a crucial contributor to the formation of ammonium-sulfate and ammonium-nitrate, the most common secondary particles[2]. European wide emission reductions of these precursor emissions will be indispensable to meet the WHO guideline level for fine particles of 10µg/m^3. Meeting this guideline level would reduce the average loss of life expectancy in Europe with almost 6 months compared to the 2005 situation. Besides these health benefits, better nature protection due to reduced deposition of nitrogen would be a co-benefit.

Netherlands **Germany** **Poland**

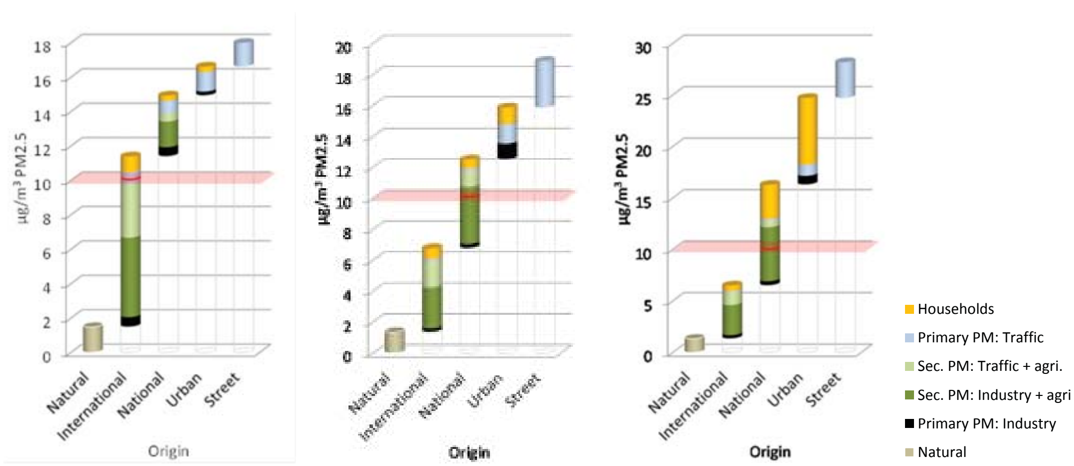


Figure 5: Composition and origin of PM2.5 concentrations at street stations. In several countries local PM2.5 levels are strongly influenced by secondary particles (ammonium sulphate and ammonium nitrate) from transboundary sources (IIASA, TSAP12, 2014)

[22] The formation of secondary organic aerosols can become more important in the future when more biogenic aerosols are released from forests as a result of temperature increase.

Possible actions at different levels to move towards WHO-guideline values for PM2.5

At the continental level:

- Ensuring that vehicle emission standards work in reality
- Effective implementation of climate & energy targets
- Emission standards for non-road mobile machinery, domestic stoves and installations for biomass burning
- Ammonia emission standards for large cattle farms

At the national level:

- Ratifaction and implementaton of CLRTAP Protocols
- Effective control on maintenance schemes for vehicles
- Srapping schemes of old vehicles and motorcycles
- Implementation of climate and energy policies
- Enforcement of emission standards for farms and domestic stoves

At the local level:

- Low emission zones to encourage early scrapping of old vehicles
- Speed limits on highways near urban areas
- Stimulation of electric vehicles
- Improved infrastructure for public transport, cycling and walking (air pollution policy embedded in healthy city designs)

Based on the proposed climate and energy measures in the EU in the context of the UN Framework Convention on Climate Change and implementation of technically available abatement measures, WHO guideline values for fine particles could become feasible in most parts in Europe in the coming decades.

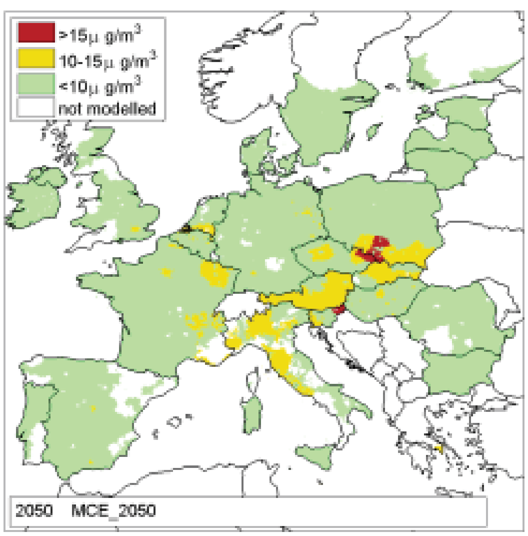


Figure 6: PM2.5 concentrations in 2050 after implementation of climate and energy policies in the EU needed to meet the 2-degrees target of the UN-FCCC and a shift towards low-meat diets. Red and orange colors show regions where WHO guideline levels still will be exceeded (Source: IIASA, 2014)

Synergies

Air pollution policy is closely linked to climate and energy policy as well as to agricultural and biodiversity policies.

Most climate policy measures will contribute to cleaner air and have health and ecosystem benefits. Pollutants like SO_2, NO_x, VOC and PM2.5 result to a large extent from the use of fossil fuels. Like in the last decades, future changes in the fuel mix and measures to increase energy efficiency will in general not only lead to a reduction in emissions of carbon dioxide, but also of SO_2, NO_x, VOC and PM2.5. Also emissions of mercury and combustion-related POPs will go down when less coal is being used.
Air pollution also has a short term regional climate effect. Some pollutants act as cooling agents (e.g. sulphates and others giving white particles), while other contribute to warming (black particles, ozone and its precursors). To balance the climate impact of air pollution policy, sufficient attention should be paid to the abatement of black particles, e.g. from diesel cars. The Euro-6 standards include such an approach. The use of biofuels is also an example where air pollution and climate impacts need to be addressed together.

Current knowledge indicates that ozone concentrations will increase in a warmer climate. In order to avoid this, more efforts would be required to abate ozone precursors in the Northern Hemisphere: in addition to current policies to reduce emissions of NOx and volatile organic compounds, reduction of emissions of methane is most effective. This would require a co-ordinated policy that goes beyond the current domain of the LRTAP Convention and would also include major polluters in Asia. Particularly, future methane emissions controls are of major importance for controlling ozone concentrations in the next decades.

Future ammonia emissions are not linked to the future use of fossil fuels, but more to the development in livestock and diets. Current knowledge indicates that ammonia emissions will increase in a warmer climate. Ammonia related problems such as the exposure of the population to secondary particles and the loss of biodiversity in nature areas will remain the responsibility of air quality managers. Some measures to reduce ammonia emissions would imply financial benefits as they include a more efficient use of nutrients. The potential of technical options to reduce ammonia emissions is significant, but more limited than for SO_2 or NO_x. Non-technical options could include a reduction of livestock densities in and around sensitive nature areas, a reduction of food waste and stimulating low-meat diets. Diets that require less meat production will lead to less manure and less ammonia emissions.

The introduction of the catalytic converters in the 1990s also required a ban on the use of leaded petrol, which drastically reduced lead related health impacts. Reduction of primary emissions of fine particles could also have co-benefits in terms of less exposure of the population to some heavy metals and persistent organic pollutants.

In some cases climate measures could lead to more air pollution, without additional measures: wood stoves, diesel cars or the use of biofuels being the most prominent examples.

Ratification

Ratification and implementation of LRTAP protocols would for many parties reduce health and environmental impacts in a more cost-effective way than with unilateral action. It would also enable a level playing field for industries, and prevent parties to compete with each other at the expense of environment and health. This can prove to be important in free trade negotiations, e.g. with EECCA countries or in settling disputes between governments and industries in the proposed Transatlantic Trade and Investments Partnerships (TTIP).

Incomplete and uncertain emission data can prove to hinder ratification of the (revised) Gothenburg Protocol, especially by EECCA countries as national emission ceilings and/or emission reduction obligations are difficult to define when emission sources are missing, or when it is unclear which abatement options are already implemented. But also for EU countries uncertainties in the effective implementation of legislation in reality can prove to be challenge for meeting national emission ceilings.

Although the costs of reducing health impacts are generally much lower in EECCA countries than in the EU or North America, the costs as a percentage of GDP are significantly higher to meet a comparable ambition level for health protection.

Further research

The LRTAP Convention offers a platform for mutual learning and finding solutions. The more parties ratify the protocols, the larger the scale of the market for cleaner technologies will become, and the lower the costs of such technologies. This offers advantages to all parties involved.

Improvement of emission inventories and projections and further harmonisation of monitoring air quality and health and ecosystem impacts can help to assess policy progress. Exploring potential synergies between air pollution policies at the local, regional and hemispheric scale, as well as with energy and agricultural policies could identify cost-effective additional measures.

A. Where are we?

A1. Health impacts of particulate matter

Reduction of emissions and the exposure of the population to particulate matter has increased the average life expectancy in Europe by almost 3.5 months between 2000 and 2010. But still in 2012, almost 600 000 premature deaths related to ambient air pollution were estimated in the UNECE region. The majority of these are due to exposure to particulate matter (PM). PM concentrations in 2005 were estimated to lead to an average loss of life expectancy of 8.3 months. In many cities, however, the loss in life expectancy from air pollution remains significantly higher than this average. Furthermore, in some areas such as Eastern Europe, the Caucasus and Central Asia, more monitoring is required to quantify the impacts to health from air pollution.

Air pollution is the largest contributor to the burden of disease from the environment, and is one of the main avoidable causes of death and disease globally. Even at relatively low concentrations air pollution poses a risk to health and due to the large number of people exposed, it causes significant morbidity and mortality in all countries. A recent international study has ranked ambient particulate air pollution as the 9th cause of disease burden globally for year 2010 (Lim et al., 2012). This ranking varies by region, and in Europe and North America, sub-regional analyses show that ambient particulate air pollution is ranked between 11th and 14th cause of death and disease. Household (indoor) air pollution also poses an important burden of disease, especially in developing countries where solid fuel combustion for cooking, heating and lighting is common practice. Furthermore, household solid fuel combustion is a significant contributor to ambient air pollution.

In 2012, exposure to ambient (outdoor) air pollution contributed to 582 000 premature deaths in the WHO European Region and in high-income North America (WHO, 2014). According to current knowledge, health effects have been calculated for the exposure to small PM (PM10: $\leq$ 10µm in diameter or PM2.5: $\leq$ 2.5µm in diameter (i.e. fine PM)), which causes cardiovascular, cerebrovascular and respiratory disease, as well as cancer (Loomis et al., 2013; WHO Regional Office for Europe, 2014). Fine PM is a useful indicator that is widely measured and used to describe the exposure to air pollution that may be responsible for the observed health effects or act as a proxy for the mix of pollutants responsible for the health effects (WHO Regional Office for Europe, 2013a).

The WHO has recently reviewed the state of the science on health aspects of air pollution (WHO Regional Office for Europe, 2013a). The importance of air pollution as a risk factor for major non-communicable diseases (such as cardiovascular diseases) has been coming to the fore in recent years due to recent research findings strengthening the existing, strong evidence on health effects of ambient air pollutants such as PM, ozone and nitrogen dioxide even further, particularly for the specific effects of nitrogen dioxide and the effects of long-term exposure to ozone.

Exposure to air pollutants such as PM and ozone continues to be a threat to public health. Increased monitoring coverage of population exposure to air pollution, especially for PM2.5, has led to improvements in estimating population exposure. More than 75.4% of the population of the cities for which PM data exist is exposed to annual PM10 concentrations exceeding the concentrations recommended in the WHO air quality guidelines (AQG) (WHO Regional Office for Europe, 2006; WHO Regional Office for Europe, 2015a). Although this proportion remains high, there have been some improvements compared to previous years, with average PM10 concentrations slowly decreasing in most countries during the last decade (EEA, 2014; WHO Regional Office for Europe, 2015b).

According to the latest assessment of the European Commission, in the European Union (EU) the health impacts of PM, the main cause of death from air pollution, have been reduced by approximately 20% between 2000 and 2010 (EC, 2013). Modelled trends in pollutant concentrations show when considering a “business as usual scenario” (baseline projection) that the impacts of air pollution will continue to decrease by 2020, when the absolute number of estimated premature deaths will amount to 340 000. Beyond 2020, and without further measures, further reductions in health impacts from air pollution are expected to progress at a considerable slower rate. On average across the EU, the baseline projection suggests a decline of the loss of statistical life expectancy attributable to the exposure to PM2.5 from 8.5 months in 2005 to 5.3 months in 2025. However, if the maximum technically feasible reduction measures would to be implemented in the EU, the loss of statistical life expectancy could be further decreased by 2030 to about 3.6 months on average.

Findings of the European Aphekom (“Improving Knowledge and Communication for Decision-making on Air Pollution and Health in Europe”) project, that used health impact assessment methods, indicate that average life expectancy in the most polluted cities in Europe could even be further increased by approximately 20 months if the long-term PM2.5 concentrations would be reduced to the WHO AQG annual concentration (Figure 1).

Recently, the Executive Body of the Convention has adopted amendments to the Convention’s 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level ozone. The revised Protocol includes, for the first time, commitments to reduce the emission of fine particulate matter (PM2.5). Furthermore, black carbon is now included in the revision as an important component of PM2.5 (UNECE, 2015).

Monitoring and modelling of air pollution concentrations are continuously reviewed. However, ground-level monitoring is very limited in countries in Eastern Europe, the Caucasus and central Asia, with only a small number of monitoring stations. There is a need to improve (i) the identification of emission sources and subsequently (ii) the monitoring network in many countries to assess population exposure and assist local authorities in establishing plans for improving air quality.

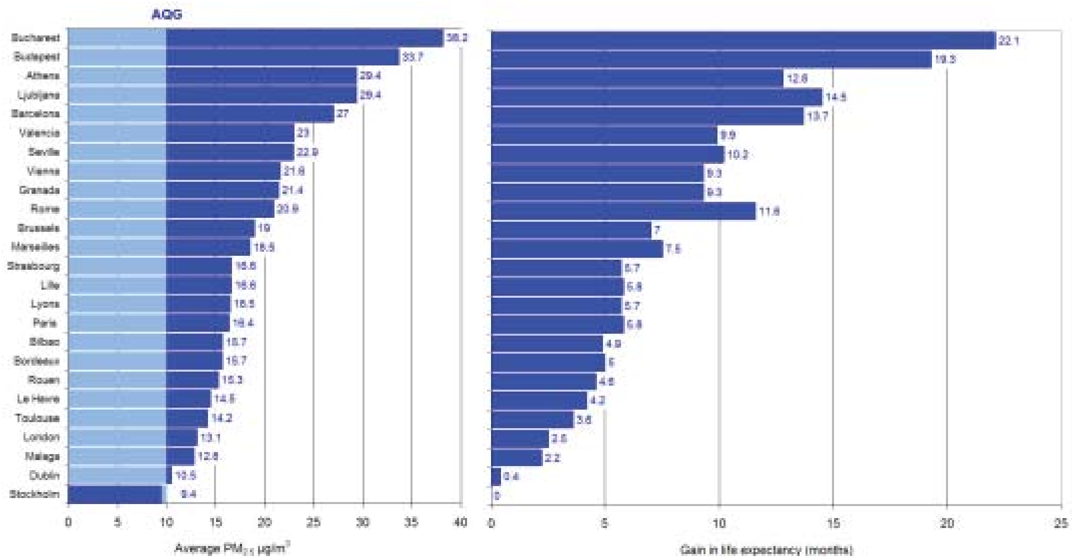


Figure A1: Predicted average gain in life expectancy [months] for people aged 30 years for a reduction in average annual concentrations of PM2.5 down to the WHO AQG annual mean concentration of 10µg/m3 in 25 European cities participating in the Aphekom project Source: Based on Aphekom Summary Report (2011)

Environmental health policy

Air pollution is amongst the top ten causes of death and disease globally. Therefore the WHO, the Organization for Economic Co-operation and Development (OECD) and the United Nations Environment Programme (UNEP) have put air pollution high on their political agenda. Moreover, cost-effective interventions exist that reduce air pollution and lead to health benefits. Broadening the cooperation of CLRTAP with other international bodies and health ministries could further stimulate air pollution policy.

In addition to the human health impacts incurred, the morbidity and premature mortality due to air pollution are associated with significant economic costs. These include, but are not limited to, the cost to society resulting from premature deaths, the costs of healthcare for the sick due to poor air quality, and the loss of productivity associated to that sickness and/or caregiving for oneself or others (Holland, 2013). Therefore, in addition to health benefits significant cost savings can be achieved through air pollution abatement. According to a recent joint report from WHO Regional Office for Europe and the OECD, the cost of the premature deaths and diseases caused by air pollution in the 53 Member States in the WHO European Region was about USD 1.6 trillion in 2010. This economic value corresponds to the amount societies are willing to pay to avoid these deaths and diseases with necessary interventions (WHO Regional Office for Europe, 2015c). In the EU, the health-related external costs from air pollution ranged between €330 billion and €940 billion in 2010, and are expected to be reduced under a business-as-usual scenario (baseline projection) to €210-730 billion in 2030 (considering € prices in 2005) (EC, 2013). The corresponding economic benefits of the proposed EU air policy package can be monetized, resulting in about €40-140 billion, while the costs of pollution abatement to implement the package are estimated to reach € 3.4 billion (per year in 2030). The impact assessment states that the monetized benefits therefore will be about 12-40 times higher than the costs (EC, 2013).

Ambient air pollution is therefore considered as the most important environmental risk factor for health and deserves particular attention. In addition to efforts under the UNECE LRTAP Convention, other United Nations organizations have put air pollution high on their political agenda, including:

- World Health Organization: In the Parma Declaration in 2010, Ministers of Health and Environment of the WHO European Region have committed to reduce exposure to air pollution, decrease diseases, and take advantage of the approach and provisions of the LRTAP protocols and support their revision, where necessary (WHO Regional Office for Europe, 2010). More recently, the World Health Assembly adopted a Resolution on "Health and the environment: addressing the health impact of air pollution" at its 68th session in May 2015 (WHO, 2015). The key aim of the Resolution is strengthening the support to Member States to amplify the health sector's ability to act in order to protect and improve public health.
- United Nations Environment Programme: The UN Environment Assembly has called for strengthening actions on air quality in 2014. The delegates unanimously agreed to encourage governments to set standards and implement policies across multiple sectors to reduce emissions and manage the negative impacts of air pollution on (i) health, (ii) the economy, and (iii) an overall sustainable development (UNEP, 2014). In addition, the UNEP hosts the Secretariat of the Climate and Clean Air Coalition (CCAC), which focuses on methane, black carbon and hydrofluorocarbons. It was created in order to raise awareness, enhance and develop actions, promote best practices, and improve scientific understanding.

Cost-effective interventions that reduce air pollution and lead to health benefits exist (WHO Regional Office for Europe, 2013b). There is consistent scientific evidence that shows that lowering air pollution concentrations results in health benefits for the population, and that these improvements occur soon (over a time period possibly as short as a year) after the reduction in pollution (Laden et al., 2006; Lepeule et al., 2012). To date, regulatory efforts have led to reduced emissions of some air pollutants in Europe and North America (EEA, 2014), which may in turn lead to a reduced population exposure and a reduced burden of disease.

The reductions in primary PM, sulphur, NOx and VOC emissions achieved to date have contributed to a reduction in PM-exposure, but the relative contribution of nitrogen related secondary particles has increased (source IIASA, Lelievelt, Nature)]. Further control measures on emissions of nitrogen compounds, especially those of ammonia would be cost effective for human health benefits and would reduce exceedances of nitrogen deposition effects on ecosystems (source IIASA, 2014).

The health impacts of air pollution are linked to emissions from various sectors, such as industry, transport, power and heat generation, and agriculture. The health sector needs to engage with a range of other sectors in order to provide advice to the other sectors on policy options that will yield the greatest benefits to health. Furthermore, air pollution can travel thousands of kilometres and cross national borders. Therefore, strengthened inter-sectorial cooperation, and actions at local, national, regional and international levels are essential to decrease the burden of disease from air pollution. The UNECE LRTAP Convention can play a crucial role in stimulating air pollution policy and fostering inter-sectorial cooperation at international level across Europe and North America, and even possibly beyond.

The overall compelling scientific evidence and significant burden of disease from air pollution provide convincing arguments for the need to take further action in all relevant sectors, to reduce emissions and as a result, improve air quality and public health.

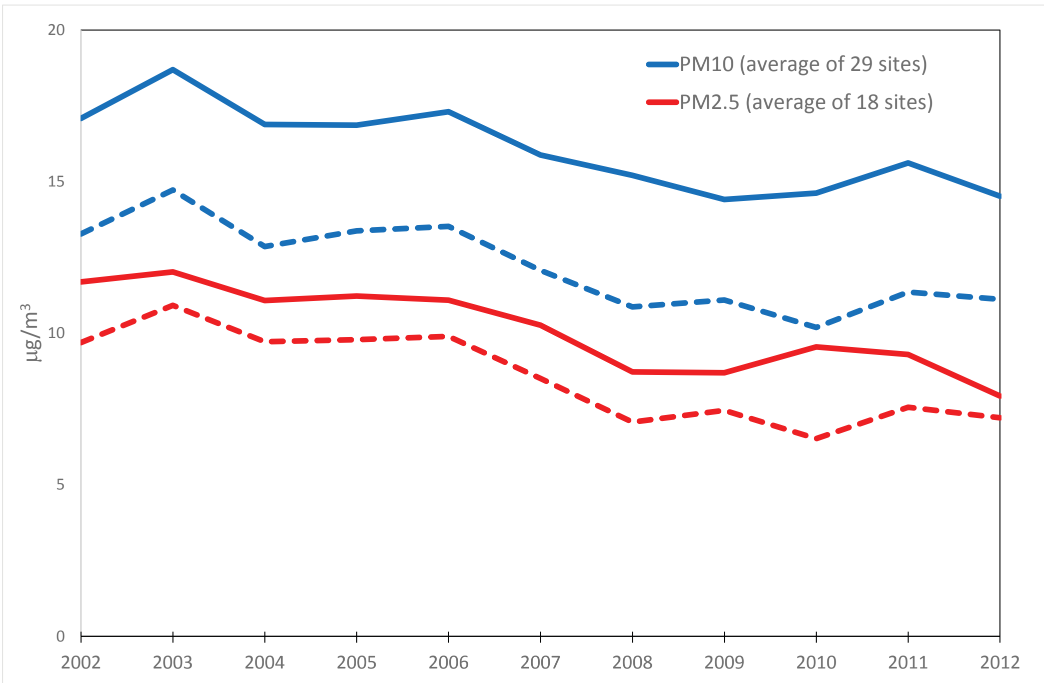


Figure A1b: Trends in the observed and modelled annual average concentration of PM10 and PM2.5 at EMEP sites. Dotted lines are modelling results

A2. Biodiversity and eutrophication

In large parts of Europe the loss of plant biodiversity due to excess nitrogen continues, despite the reduced deposition of nitrogen.

The emissions of nitrogen oxides and ammonia have over the 20th century caused significant changes in European ecosystems. Low fertility heathlands have been converted to grasslands and many rare plant species adapted to low nitrogen availability have disappeared. In large parts of Europe the loss of biodiversity due to excess nitrogen continues, especially in areas with high density of livestock and consequently high ammonia deposition. Monitoring of natural ecosystems and experimental studies show nutrient imbalances, a declining biodiversity and elevated nitrate leaching. (Sutton et al. 2011). Figure B1 shows the decline in species richness in acid grassland with increasing nitrogen deposition across Europe, indicating a 50% reduction in species richness as nitrogen deposition increases by 30 kg ha^{-1} annually (as N) (Stevens et al., 2010).
The deposition of nitrogen compounds exceeds the critical loads over large parts of Europe and measures taken so far have not been significantly changed the situation (ref. Hettelingh et al, 2015).

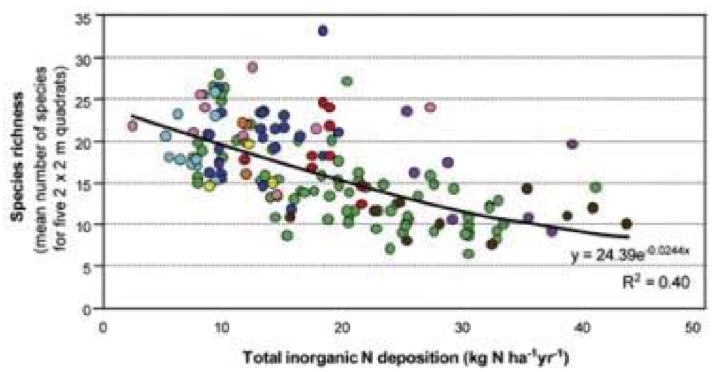


Figure A2: Relationship between species richness of acid grasslands in the Atlantic region and N deposition. (Stevens et al. 2010)

Emissions of nitrogen compounds from combustion processes in Europe have declined by about half since their peaks around 1990, while emissions of ammonia from agriculture have declined by a quarter (Figure A2). The downward trend in NOx emissions is also reflected in monitored concentrations of oxidized nitrogen compounds in the atmosphere and precipitation (Figure A3). Significant downward trends have also been observed for ammonium in air and precipitation in line with emission trends. (Figure A4).

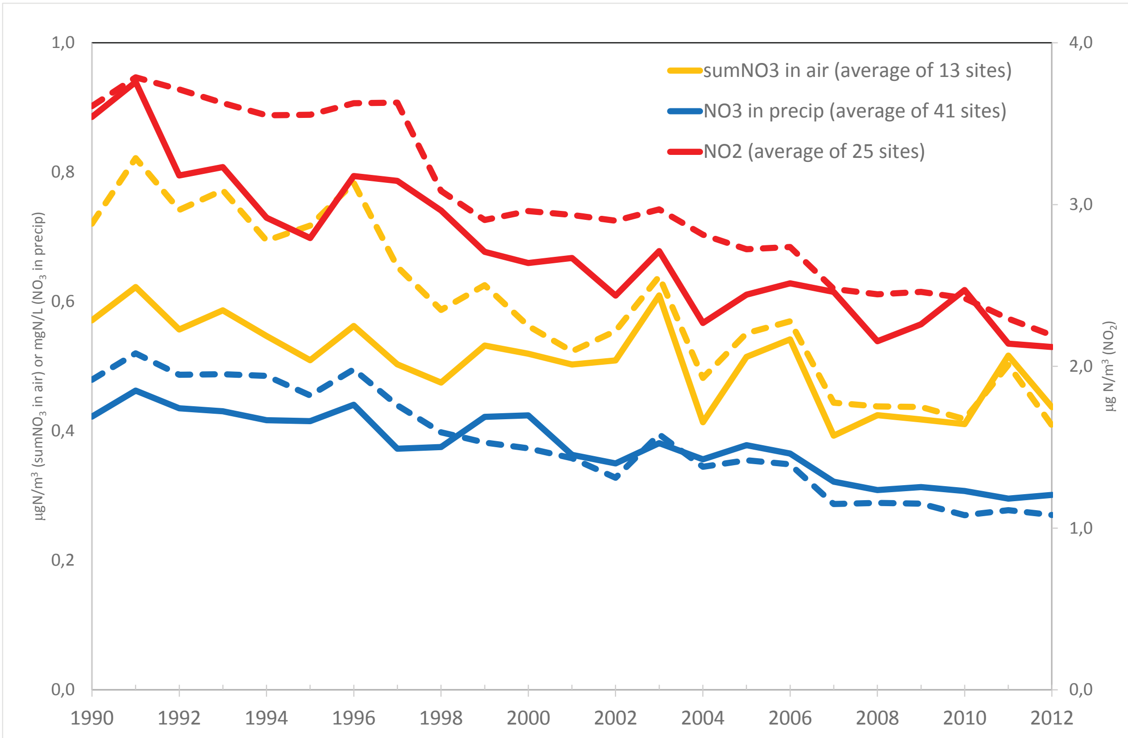


Figure A3**:** The observed and modelled annual average concentration in oxidized nitrogen components in precipitation and air at EMEP sites with measurements for at least 75% of the time period, 1990-2012. Dotted lines are modelling results

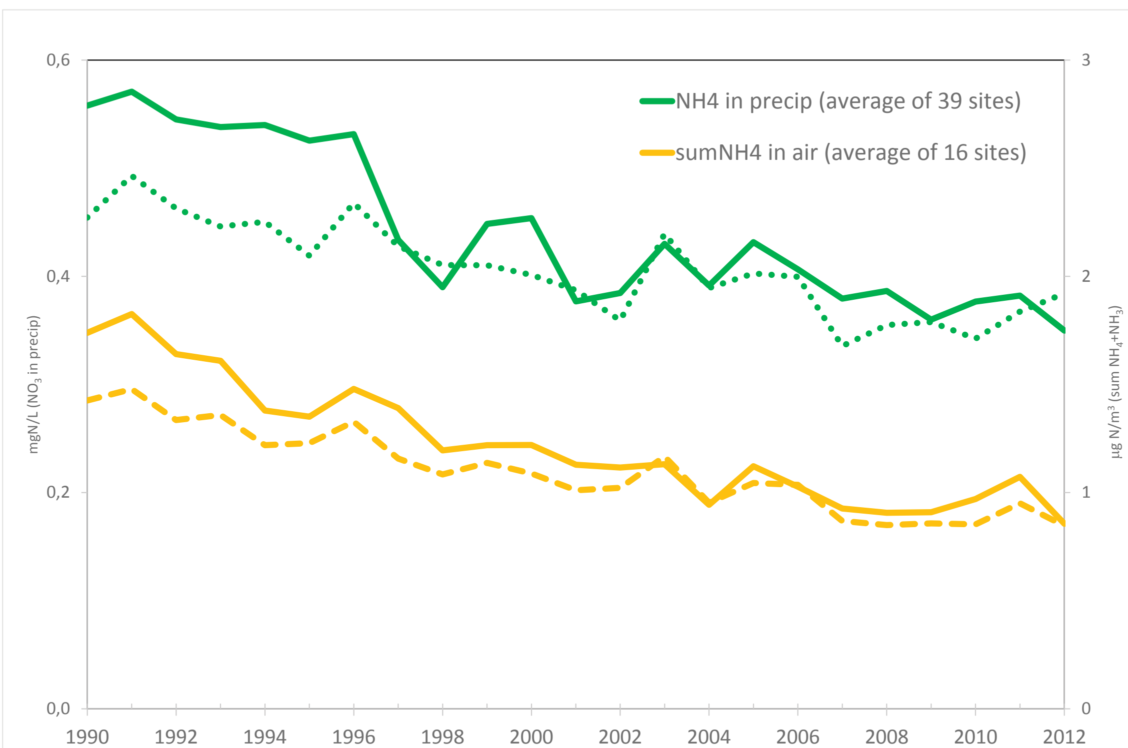


Figure A4: The observed and modelled annual average concentrations in reduced nitrogen components in precipitation and air at EMEP sites with measurements for at least 75% of the time period, 1990-2012. Dotted lines are modelling results

The present controls agreed within the 1999 Gothenburg Protocol and its amendment will further reduce nitrogen deposition, but there is no evidence of ecosystem recovery from the reduced emissions to date and it is unclear how long it will take for ecosystems to respond to reduced N deposition. The current commitments are insufficient to prevent further accumulation of nitrogen in ecosystems, presenting a growing risk to ecosystem stability in the longer term. In particular substantial reductions of ammonia emissions were lacking. The trend in areas at risk due to eutrophication between 1980 and 2030 (Fig. A5) shows that the risk of eutrophication is persistent. The area at risk of eutrophication decreases from 75 % in 1980 (80 % in the EU28) to about 55 % in 2020. In 2030 a further reduction to about 49 % under MFR2030 could be technically feasible (Hettelingh et al., 2015).

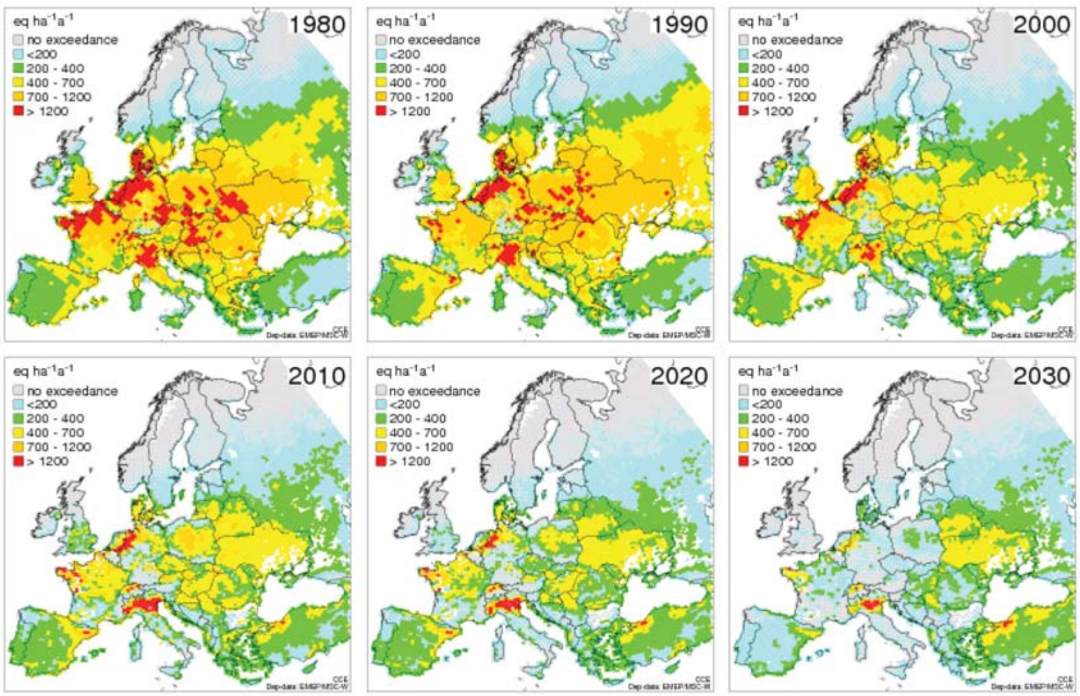


Figure A5: Average Accumulated Exceedance (*AAE*) of computed critical loads for eutrophication in 1980 (*top left*), 1990 (*top centre*), 2000 (*top right*), 2010 (*bottom left*), 2020 under the revised Gothenburg protocol (GP-CLE scenario) emission reduction agreements (*bottom centre*), and in 2030 when applying Maximum Feasible Reductions (*bottom right*) (Source: Hettelingh *et al.*, 2015)

Deposition of nitrogen is also a driver for acidification and its relative role has increased due to the successful control of sulphur emissions. In addition nitrogen oxides and ammonia contribute to the formation of particles and may make up a significant part of the PM2.5 concentrations in Europe and North America. NOx is also a key precursor for the formation of photochemical oxidants, in particular ozone. .The global nitrogen (N) cycle has been severely altered over the last decades. Of the total annual fixation of atmospheric nitrogen of 413.000 kt-N, 51% results directly from human activity. Scenarios for the time up to 2100 indicate that the nitrogen problem will cause an increasing threat to human health, ecosystems and climate. The nitrogen cycle is very sensitive to changes in climate as shown in figure A6, with substantial increases in emissions as the climate warms in the next few decades. Coordinated policies to mitigate air quality and climate change through reductions in emissions of NO_x and

NH_3 would avoid large increases in emissions of NH_3 emission during the later decades of this century. (Fowler et al 2015)

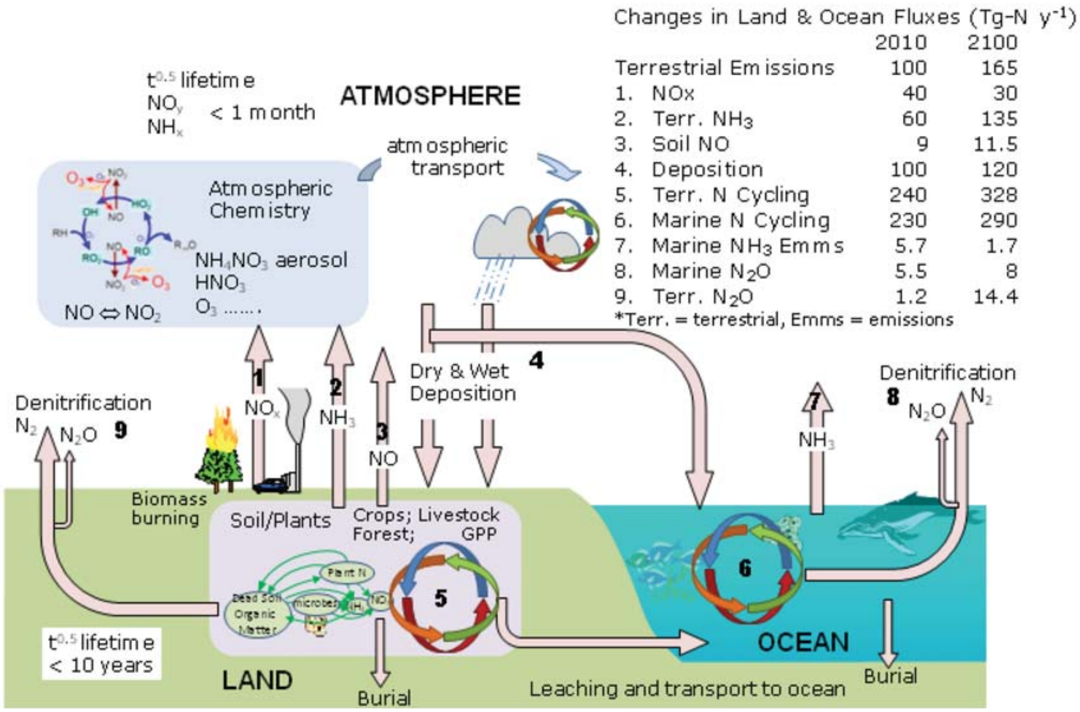


Figure A6: Changes in the major fluxes and in the terrestrial, marine and atmospheric processing of reactive nitrogen (N) between 2010 and 2100 (Fowler et al 2015) (1 Tg = 1000 kt)

Further control measures on emissions of nitrogen compounds, especially those of ammonia would be cost effective for human health benefits and would reduce exceedances of nitrogen deposition effects on ecosystems. The reductions in sulphur and VOC achieved to date have contributed to a reduction in PM, but this has also increased the relative contribution of nitrogen emissions to the human health effects of particulate matter.

Thus the overall message on nitrogen is that the useful steps taken to reduce emissions of nitrogen compounds to date have been insufficient to provide conditions in which ecosystems can begin to recover and that further reductions are necessary. Furthermore, the relative contribution of nitrogen compounds to particulate matter has grown as sulphur emissions have declined and with the emphasis on effects of PM on human health, further reductions in emissions NH_3 and NO_x have become a priority in Europe, both nationally and for the inter-country exchange of pollutants. Lastly the effects of climate on emissions of nitrogen compounds may substantially offset the reductions in emissions to date and new measures to reduce emissions would avoid much larger costs later.

A3. Acidification of lakes and forest soils

Since the peak in 1980, European emissions of sulphur have been reduced by 80%. Although recovery is progressing the acidification problem is not solved.

In the 1960s and 1970s there was growing concern about the effects of air pollution on the environment. Thousands of lakes and streams in Norway, Sweden, Finland and other acid-sensitive parts of Northern Europe had lost or damaged fish populations (Tammi et al. 2003). Forests were threatened in large regions of central Europe. Substantial damage to materials, including historic buildings and cultural monuments, was also reported. Acid deposition was also a concern in eastern North America. Acid rain damage was observed in the Muskoka and Haliburton lakes areas of Ontario, in southern Quebec, in much of northern New York State and New England, and as far east as Nova Scotia.
In response to the public concern about the adverse effects of air pollution, countries of the UNECE region adopted in 1979 the Convention on Long-range Transboundary Air Pollution (CLRTAP). The first international agreement to reduce the emissions of acidifying compounds came with the 1985 Sulphur Protocol, which specified a 30% reduction in Sulphur emissions in 1993 relative to 1980 levels. Subsequent protocols specify further reductions in both Sulphur and Nitrogen emissions, and in 2010 the deposition of S had decreased by nearly 90% in Europe relative to 1980 (Figure A8).

Today we are facing a situation with recovering lakes and streams. The exceedance of Critical Loads for acidification has decreased substantially and significant exceedance is only observed in limited parts of Europe. Acidified soils have also started to recover. Water quality is improving as demonstrated by increased pH and buffering capacity (acid neutralizing capacity) (Garmo et al., 2014), and recovery of acid-sensitive sediment-dwelling insects and snails is taking place. The salmon which was almost extinct in many rivers in Norway is now returning, partly because of remediation measures such as liming and fish stocking. In many lakes, fish populations are recovering but as for the rivers, this development is strongly promoted by liming and fish stocking. Norway uses annually over €10 million for liming of surface waters. However, soil and surface water acidification remains an issue in the most sensitive areas in Nordic countries, the UK and central Europe. Recovery from acidification of acidified soils and waters will take decades to centuries, because of depleted buffers of base cations in soils, which recover through the slow process of mineral weathering. Further reductions in N and S emissions will improve the situation and decrease time for recovery.

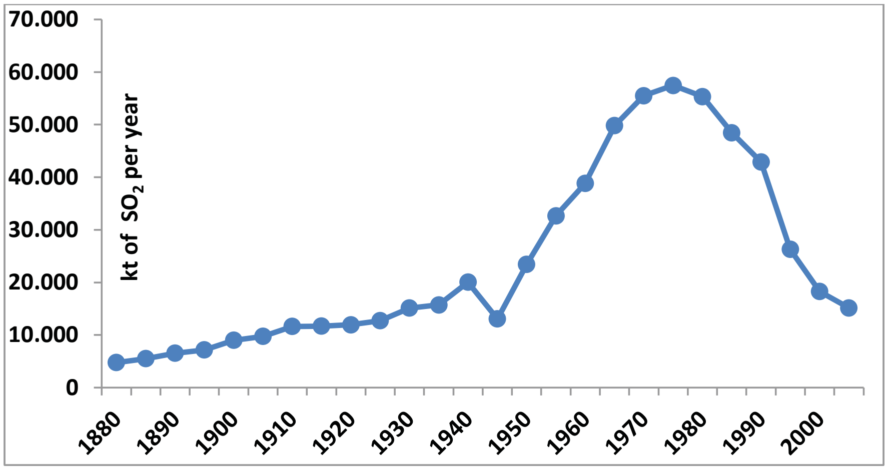


Figure A8: Emissions of Sulphur in Europe Sulphur dioxide (1000 tonnes)-showing the progressive decline in emission resulting from the succession of UNECE_LRTAP protocols 1983, 1987, 1991,1998, 1999. Reference,

The emission reductions in Europe over the last 25 years have also resulted in a corresponding decrease in atmospheric concentrations and deposition (Figure A9). The downward trend has been larger for sulphur dioxide than for particulate sulphate and for sulphate in wet precipitation. The figure also shows that there are good agreements between monitored and modelled concentrations of sulphur in air and precipitation.

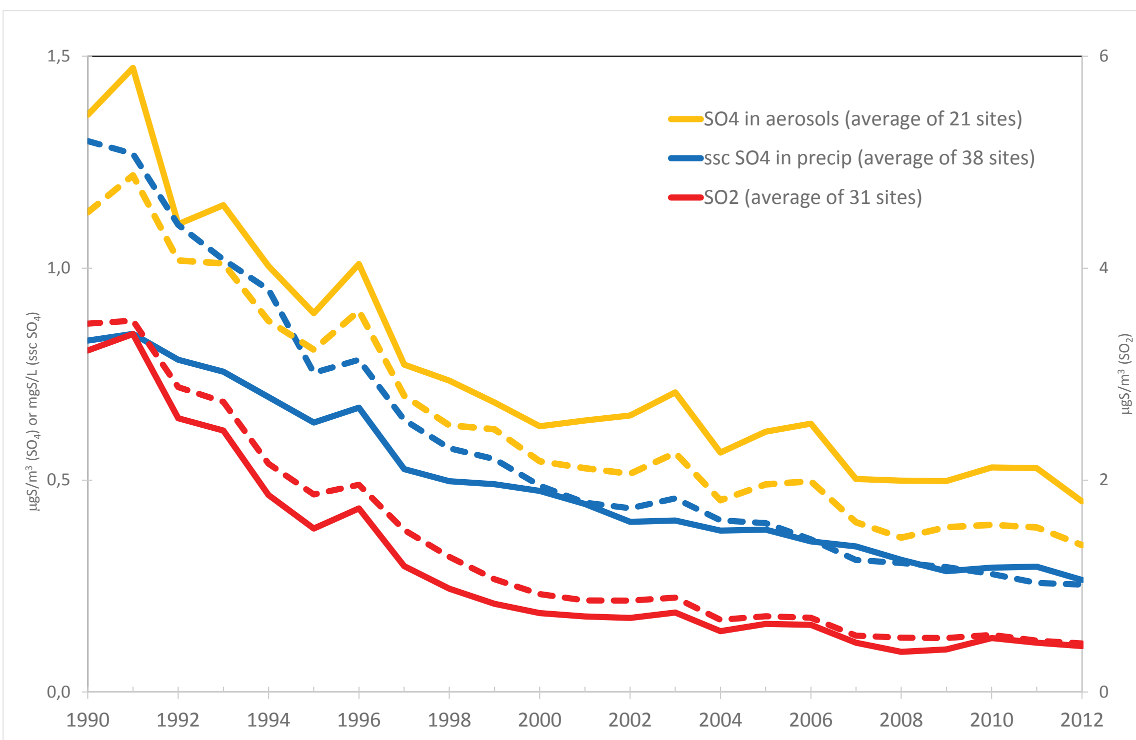
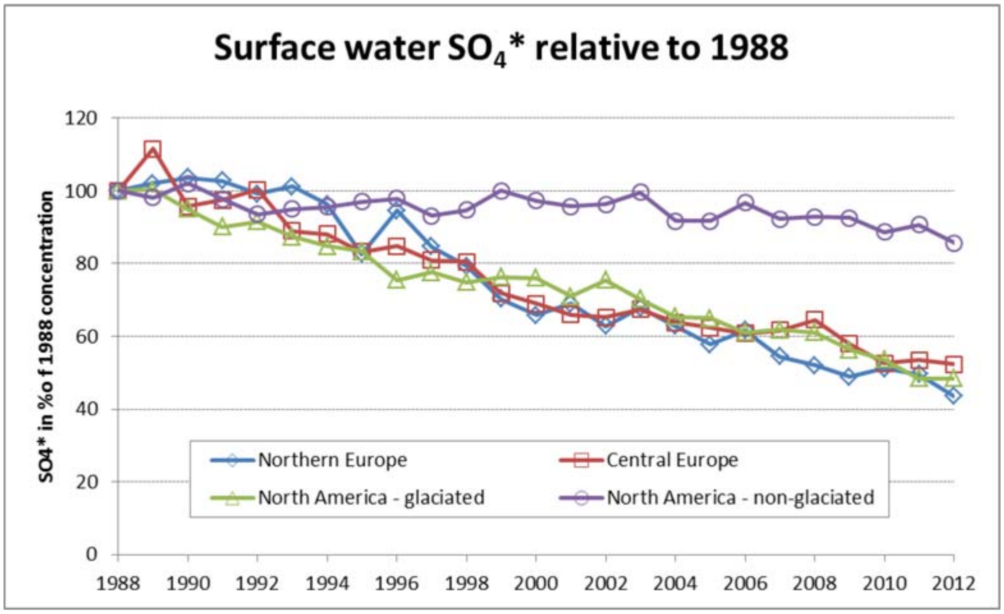


Figure A9: The observed and modelled annual average concentration in sulphur components in precipitation and air at EMEP sites with measurements for at least 75% of the time period, 1990-2012. (MSC-W, WGE Trends report). The figure includes both monitored and modelled data (dotted lines) showing that there is quite good agreement between monitored data.

These reductions in emissions have also resulted in substantial improvements in freshwater and terrestrial ecosystems (Figure A10). The strongest evidence that emission control programmes are having their intended effect comes from long-term records from monitored lakes and streams (ICP-Waters data). Concentrations of sulphate have decreased, the acidity has decreased and waters are more suitable for fish populations.



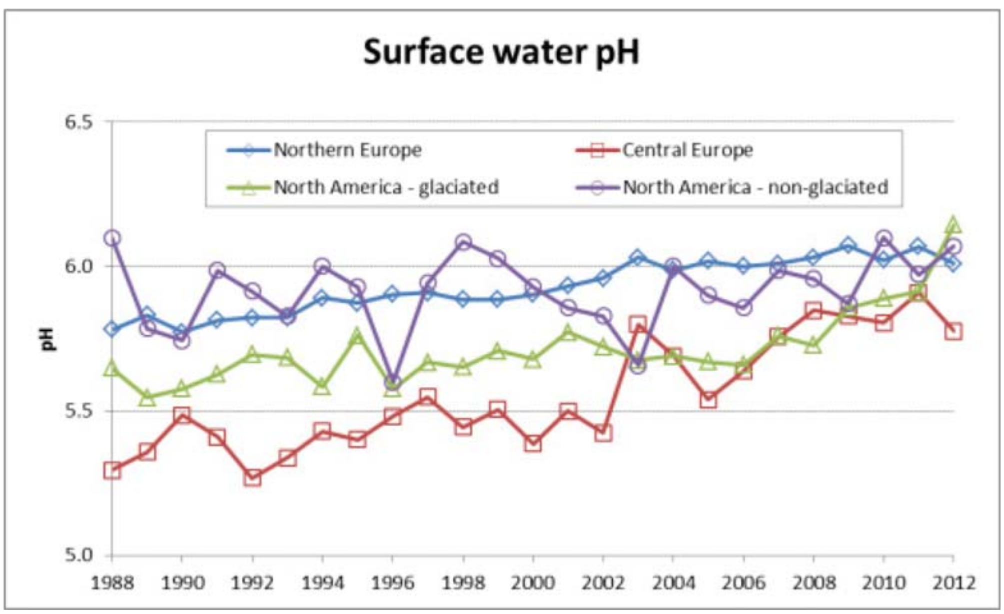
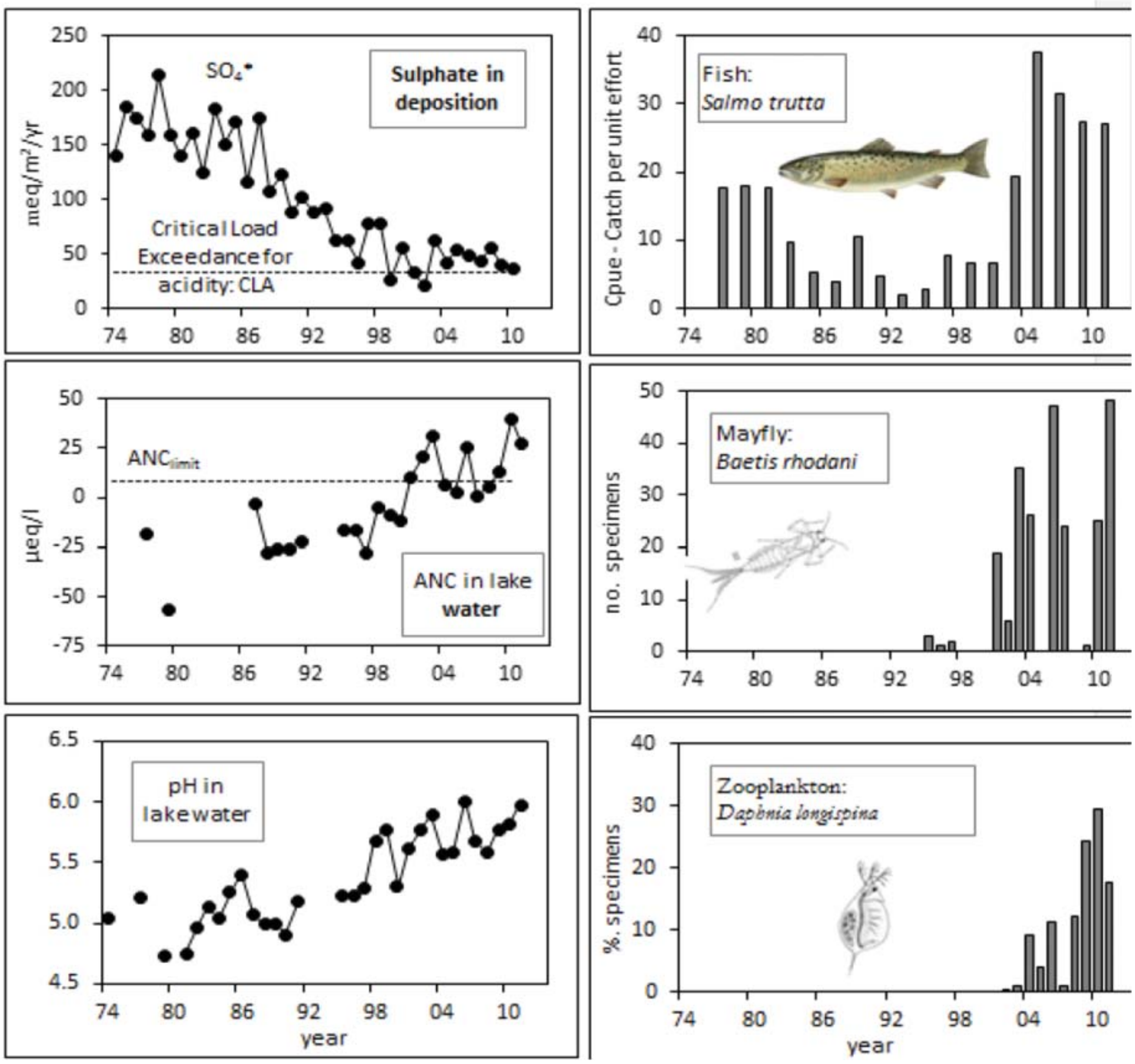


Figure A10: Trends in surface water chemistry at ICP Waters sites 1988-2012. Shown are the mean concentrations of non-marine sulphate (SO_4*) and pH at 22 sites in northern Europe, 21 sites in central Europe, 37 sites in glaciated areas of eastern North America, and 7 sites in non-glaciated areas of eastern North America. Source: Garmo et al., 2014 (WASP) and Garmo et al, 2015. Chemical and biological recovery in acid-sensitive waters: trends and prognosis (ICP Waters report 119/2015). Oslo: Norsk institutt for vannforskning 2015 (ISBN 978-82-577-6582-8) 97 s. NIVA-report (6847)

An example from Norway

Recovery from acidification at Lake Saudlandsvatn, Norway. As S deposition has decreased, the acid neutralising capacity (ANC and pH have increased) in the lake, and the populations of three sensitive species have begun to recover (modified from Hesthagen et al. 2011).



Data from T. Hesthagen, NINA (fish), NIVA (water chemistry), NILU (deposition),UiB (invertebrates)

Recent CTRTAP protocols have been formulated to maximise the environmental benefits of measures to reduce the emissions of S and N. The approach has been based on the use of Critical Loads (see text box) for acidification eutrophication and for the effects of ozone on ecosystems. .

Critical load and exceedance

Critical loads are derived to characterise the vulnerability of an ecosystem in terms of atmospheric deposition. The critical load for acidity is defined as ”the highest deposition of acidifying compounds that will not cause significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (Nilsson and Grennfelt 1988).

Exceedance occurs when the deposition is greater than the critical load. Maps of critical loads and exceedance have been made for various ecosystem types and for various years.

Over the years the methodologies as well as the geographical resolution have been improved due to new scientific findings as well as improved resolution in modelling and mapping.

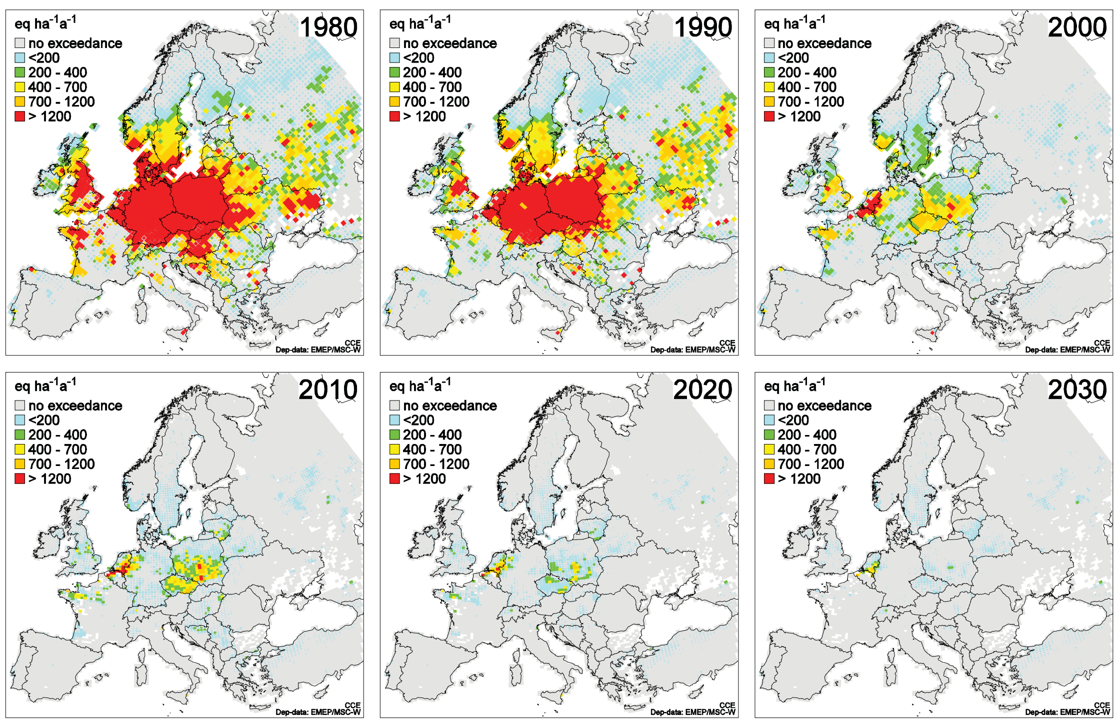


Figure A11: Average Accumulated Exceedance (AAE) of computed critical loads for eutrophication in 1980 (top left), 1990 (top centre), 2000 (top right), 2010 (bottom left), 2020 under the revised Gothenburg protocol (GP-CLE scenario) emission reduction agreements (bottom centre), and in 2030 when applying Maximum Feasible Reductions (bottom right) (source: Hettelingh et al, 2015)

The trend between 1980 and 2030 of European ecosystem areas where critical loads for acidification are exceeded (Fig A11) illustrates the decrease of the area at risk. The area at risk diminished from about 30 % in 1980 to about 2 % in 2020 under the revised Gothenburg Protocol including the implementation of current legislation. A further decrease to 1% could be achieved in 2030 when Maximum Feasible Reductions are applied (Hettelingh, 2015).

The recovery of acidified ecosystems will take time. The delay is to a large extent dependent on the accumulated sulphur in soils and to what extent and at which rate it will be released. Experiments, observations and model calculations indicate that it will take decades for ecosystems to recover.

The control of emissions of sulphur has during the last decade not primarily been driven by acidification but rather by the role of sulphate particles as a main contributor to the PM2.5 in the atmosphere. It is realistic to assume that this will continue to be the situation in the future.

Emissions of S and N compounds also cause damage to materials in particular corrosion. Long term monitoring show that the rate of corrosion has decreased in Europe in parallel with the decrease in emissions (Figure A12).

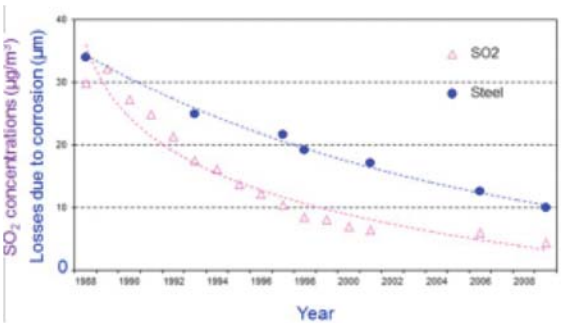


Figure A12: Trends in average corrosion rates and SO_2-concentration between 1998 and 2008 at 20 ICP monitoring sites in Europe. (Tidblad et al. 2014)

Emission reductions were not only driven by end of pipe control. The close connection to energy and energy policies has been important for the overall outcome of the emission reductions over the last decades. Historical energy balances, along with population and economic growth data, were used to quantify the impacts of major determinants of changing emission levels, including energy intensity, conversion efficiency, fuel mix, and pollution control (Figure A13). The study, covering the period from 1960 to 2010, shows that 75% of the decline in SO_2 emissions in Western Europe emanated from a combination of reduced energy intensity and improved fuel mix. The importance of direct air pollution abatement measures have been more important in Western Europe compared to Eastern Europe where the transition towards a market economy in the 1990s played a dominant role in reducing emissions (Rafaj et al 2014).

A world avoided

Without measures sulphur emissions in Europe would have more than doubled over the past 30 years. Technological solutions such as flue gas desulphurization, low-sulphur fuels and catalytic converters in cars were applied and the costs became lower as more countries applied these cleaner technologies. Environmental measures contributed to one-third of the decoupling between production and consumption growth and the development of emissions. Energy policy and general technological progress also played a significant role in decoupling production and consumption growth from the development of emissions: coal was substituted by gas and non-fossil energy and products and production processes became more energy efficient. Also in the future air pollution trends will be influenced by both environmental measures and energy policy.

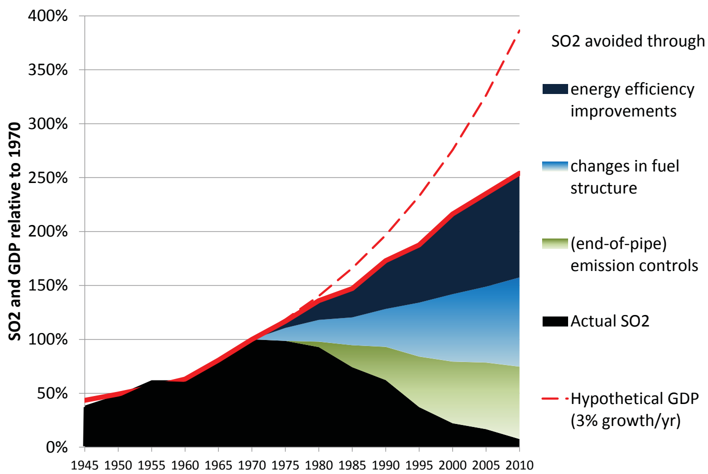


Figure A13: Determinants of reductions in SO2 emissions in Western Europe. Actual SO2-emissions in Western Europe did not increase at the same rate as GDP. Decoupling was the result of end-of-pipe abatement measures, changes in fuel mix and increased energy efficiency. Source: Rafaj et al, (2013) Climatic Change 24(3)477-504, (2014) Sc.Tot. Env. 414

If no decoupling of economic growth and air pollution trends would have occurred, the total exceedance of the critical loads for acidification in Europe would have been 30 times higher than the current exceedance. The total exceedance of the critical loads for nitrogen would have been 3 times higher. Average PM2.5 exposure would have reached levels that are currently measured in the Po-valley. Health impacts from PM-exposure would have been 3 times higher and 600.000 more people would have died prematurely. Compared to this hypothetical world avoided 12 months of average life expectancy has been gained. The health impacts from ozone would have been 70% higher and ozone damage to crops would have been 30% higher. Model studies suggest a strong influence of the rising hemispheric background on ozone impacts to crops.

A4. Ozone trends and impacts on health and ecosystems

There is evidence from models and observations that as a result of emission reductions peak concentrations of ground-level ozone started to go down at a number of locations during the last decade. However, due to large inter-annual variations, a 10-year period is not long enough to detect trends at many other locations. Average concentration and other ozone metrics during the summer do not show a clear decline. In particular in Asia, ozone precursor emissions (including methane) have been increasing, contributing to background ozone in Europe. Less ozone is taken away by NOx-emissions close to the source regions. Ozone is therefore still a threat to public health, crops and forests.

Ozone (O_3) is formed by the photochemical transformation of nitrogen oxides (NOx), methane (CH_4), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). Differences in the magnitude and distribution of precursor emission, climatic conditions and chemical composition, lead to significant regional differences in ozone concentrations.

Short-term (few hours) exposure to ozone is associated with mortality and respiratory morbidity (REVIHAAP, 2013). The EU Ambient Air Quality Directive target value for ozone specifically addresses short-term health risks using a maximum daily 8-hour mean ozone concentration of 120 µg m^{-3} (or 60 ppb) not to be exceeded more than 25 times a year. The WHO advisory guideline value is 100 µg m^{-3} (or 50 ppb) for a daily maximum 8-hour mean.

Monitoring of ozone at rural and urban sites throughout Europe shows that episodes of high concentrations of ground-level ozone occur over most parts of the continent every summer, during warm and stagnant weather conditions (Figure A14a), and EU O3 target values are regularly exceeded in Southern and Central European countries. Measured and modelled SOMO35, an indicator for long-term risk of ozone health impacts, also display higher values in Southern Europe (Figure A14b).

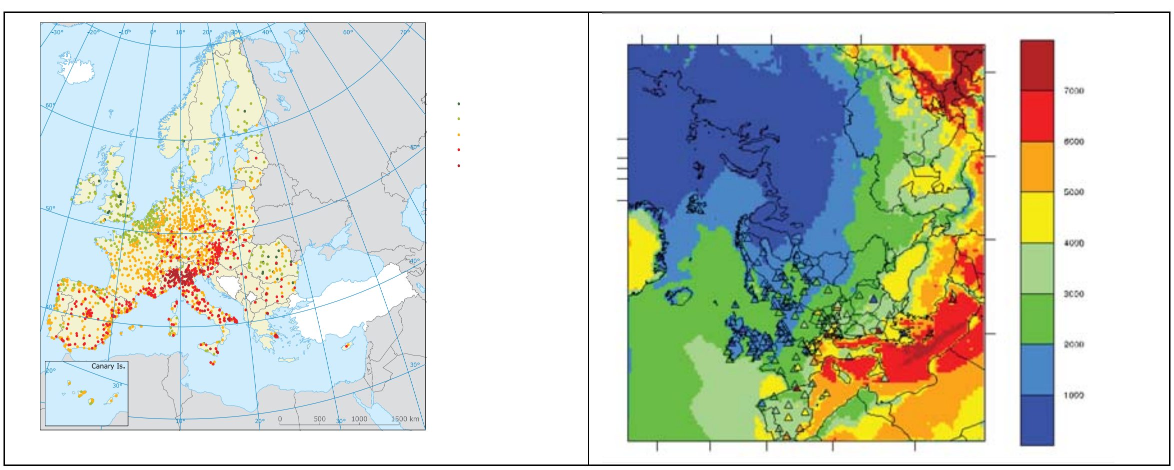


Figure A14: The 93.2 percentile O_3 concentrations (25 days with highest ozone levels) in Europe in 2012. Light and dark red colours indicate the exceedance of 120 ug m^3 (60 ppb) during more than 25 days per year. Source: EEA, 2014. b) EMEP model calculations (for the year 2013; EMEP, 2015) of SOMO35 [ppb days] (the annual sum of the maximum of 8 hours running average ozone over 35 ppbv; see http://www.emep.int/mscw/SR_data/definitions.pdf), together with observations (triangles). [Figure A14b will be updated- Hilde Fagerli]

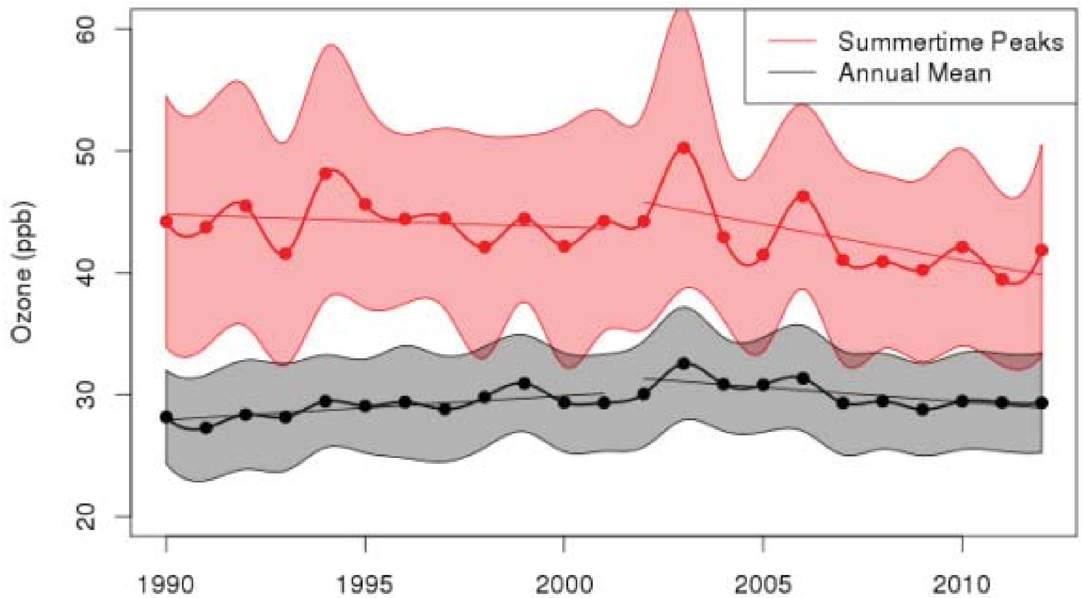


Figure A15: Evolution of ozone peak (summertime – JJA – average of daily maxima) and annual mean at EMEP monitoring stations. Shaded areas indicate the 1**σ st**andard deviation. Trend lines are indicative for the periods 1990-2002 and 2002-2012. Data include a subset of 54 EMEP stations, with at least 75 % data coverage. Source: preliminary analysis of EMEP TF MM, TFMM 2015.

Epidemiological studies provide accumulating evidence of mortality related to long-term ozone exposure (Revihaap, 2013), although it is currently not possible to establish a lower threshold for absence of effects. An analysis at 6 coastal, rural and mountain-top sites in Europe showed that mean annual ozone concentrations have increased by 0.3-0.7 ppb yr^{-1} through much of the 1980-1990s, but has either levelled off or slightly decreased since 2000 (Cooper et al. 2014). Simpson et al. (2014), using a subset of 14 'screened' EMEP stations and comparing 1990-1999 and 2000-2009, found generally increasing ozone concentrations of 0.1-0.4 ppb yr^{-1} up to the 95th ozone percentile, and ozone reductions of 0.5 to 1.5 ppb yr^{-1} above the 95th percentile. Analysis of an extended set of observations from the EMEP regional network conducted by the Task Force on Measurement and Modelling (Figure 2) show that in the period 2002-2012 summer peak ozone concentrations significantly declined, while in the preceding decade (1990-2001) the declines were smaller and mostly not significant. Ozone annual mean concentrations somewhat increased in the 1990s and levelled off in the 2000s. Other studies (e.g. EEA, 2014) confirm a declining trend in the 2000s in peak ozone in parts of Europe, but trends were only significant at 27 % of the stations. Thus, while summer peak ozone values have come down at a number of locations, likely as a result of emission reductions, these studies indicated that a similar decline in mean ozone levels was not observed. Likewise, country-averaged SOMO35 did not change between 2000-2002 and 2010-2012; WGE trend report, 2015).

Under environmental conditions conducive to high ozone uptake, ozone damage to vegetation occurs during the growing season at concentrations of 30 ppb or lower. Effects include visible leaf-injury (Figure A16), increased or pre-mature die-back and reduction in seed production and growth of sensitive species, including trees, (semi-) natural vegetation, and several important crops, including wheat, soybean and rice (Ainsworth et al., 2012, Mills and Harmens, 2011).

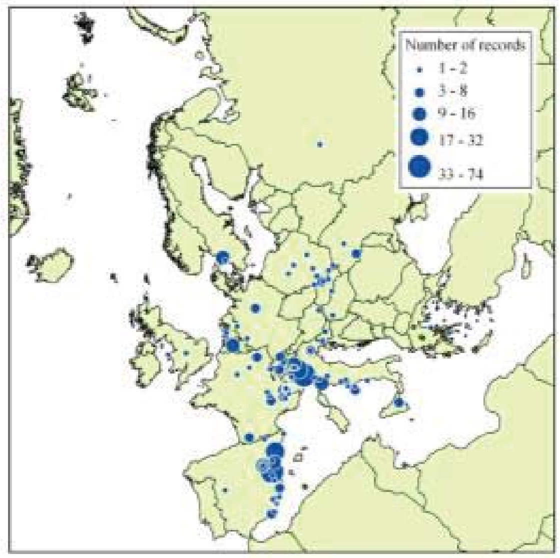


Figure A16 (a) Visible ozone injury symptoms on wheat (*Triticum aestivum*) and (b) Locations of records of visible injury attributed to ozone on crops, (semi-)natural vegetation and shrub species (1990 – 2006, Mills et al., 2011).

A variety of methodologies are used to estimate ozone damage to crops. A method that has been widely used previously in Europe is the empirical indicator AOT40 (growing season ozone above a threshold of 40 ppb). Globally (based on AOT40), ozone is estimated to account for yield losses of between 3% and 12% for the major staple crops (Van Dingenen et al., 2009). More recent ozone flux-based estimates, taking into account impact of environmental conditions on ozone uptake, show wheat yield losses to be 4.6 billion Euro in the EMEP region, equating to a yield loss of 13%, with the highest economic losses found in important wheat growing areas in western and central Europe, and ca. 40% in EECCA and SEE countries alone (Figure A17; Table 1).

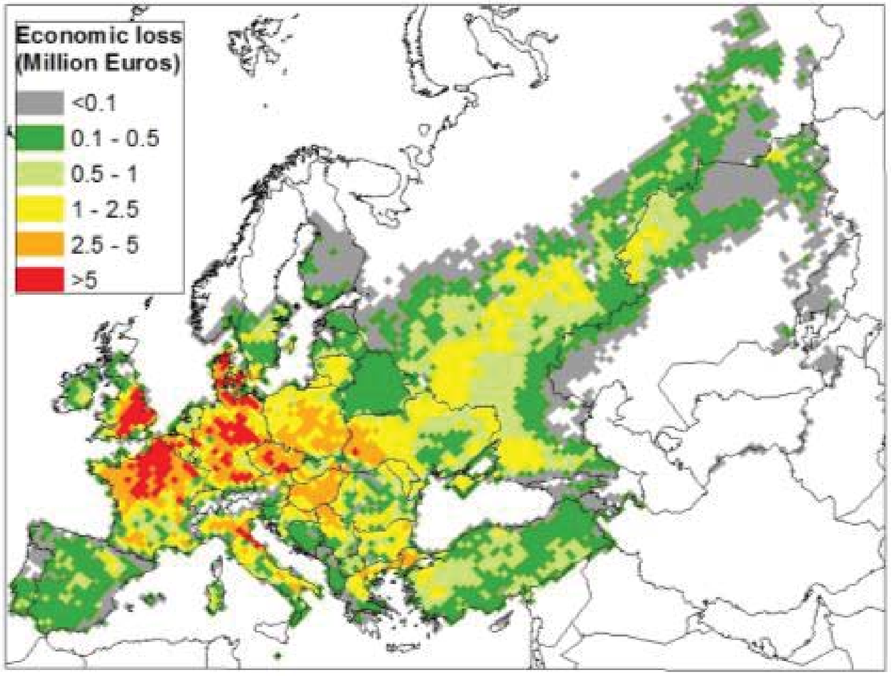


Figure A17: Wheat yield losses (in million Euro per 50 x 50 km grid square), using rain-fed wheat production values for 2000 (GAEZ; http://www.fao.org/nr/gaez/en/), calculated average ozone flux for crops (EMEP; http://emep.int/mscw/index_mscw.html) and average wheat prices for the period 2007 to 2011.

Table 1: Wheat yield losses (in million Euro per 50 x 50 km grid square), using rain-fed wheat production values for 2000 (GAEZ; http://www.fao.org/nr/gaez/en/), calculated average ozone flux for crops (EMEP; http://emep.int/mscw/index_mscw.html) and average wheat prices for the period 2007 to 2011.

	EMEP region	EU28+CH+NO	SEE[1]	EECCA[2]
Total production loss (million t)	23.7	15.4	2.8	6.7
Economic loss (billion Euros)	4.6	3.0	0.5	1.3
Percentage yield loss	13.2	14.6	10.7	12.0

[1] Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Macedonia, Montenegro, Romania, Serbia, Slovenia and Turkey

[2] Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan

Do we understand why peak ozone started to come down at a number of locations and average ozone not, despite a 40% reduction in European emissions of ozone precursors from 1990-2013 [EMEP, 2015]? There are several factors that need to be considered. Firstly, there are substantial natural variations of ozone between years and even decades. Long, and high-quality observational time series are needed to detect changes, and unfortunately such measurement data are less abundant before the year 2000. The period since 2000 is not long enough to detect trends at many other locations. To detect ozone changes, it is of high-importance that observations are continued in the coming decade. Secondly, decreasing NOx emissions can lead to increases in ozone concentrations (especially affecting the lower/middle O_3 concentration range) close to the emission source, while the benefit in improving air quality will only be felt at some distance away from the source. Models qualitatively can reproduce this phenomenon, but quantitative understanding requires high-resolution modelling and reliable information on historical emission inventories and intercontinental ozone inflow (Colette et al., 2012). Thirdly, ozone changes are variable across the world (Figure A18), and inflow conditions of ozone into Europe and North America may have changed [Wild et al., 2012; Verstraete et al., 2015; Doherty et al., 2015]. Strong and continued increases of ozone were observed in Asia and at the west coast of North America since 1990, while trends were mixed at other locations. Since tropospheric ozone has a lifetime of about 20 days, it can be transported across the Northern Hemisphere, and ozone produced from emissions in other regions can contribute to ozone concentrations in Europe. Natural large-scale ozone variability, but also changing emissions in the Northern Hemisphere are likely contributing to the changing inflow conditions. Analysis performed by the Task Force Hemispheric Transport indicates that declining ozone contributions from air pollutant controls in North America have been compensated by increases from Asia and other part of the world, and by increases of methane emissions (Figure A19). In the next decades, methane emission controls will increasingly determine whether ozone will further decline or not (see section B3).

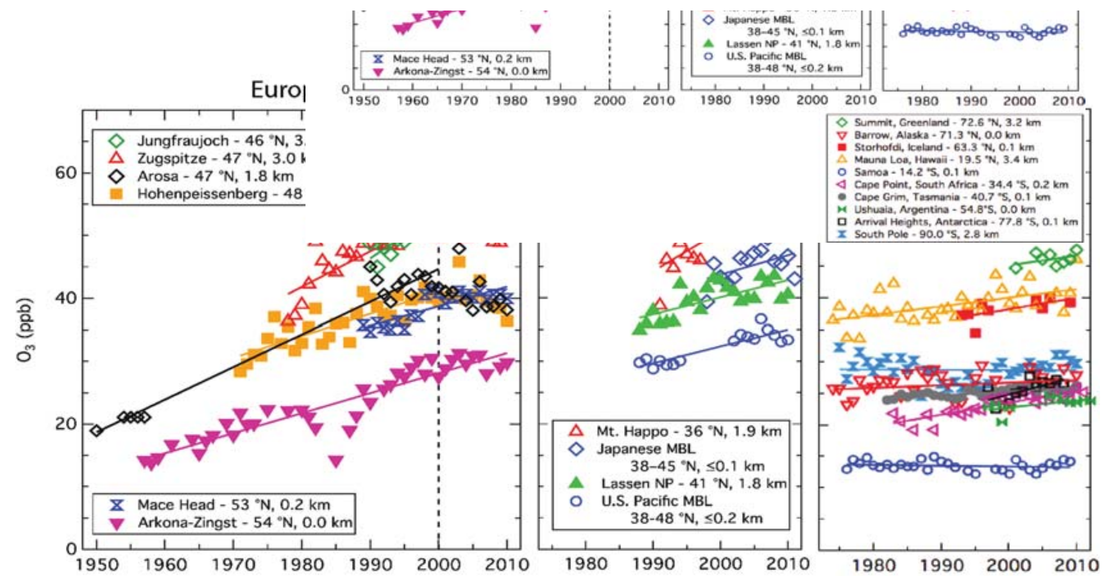


Figure A18: Surface ozone time series at several rural sites around the world. Trend lines are fit through the yearly average ozone values using the linear least-square regression method. Trend lines in Europe only extend through 2000 when the positive trend appears to have ended. From Cooper et al. (2014).

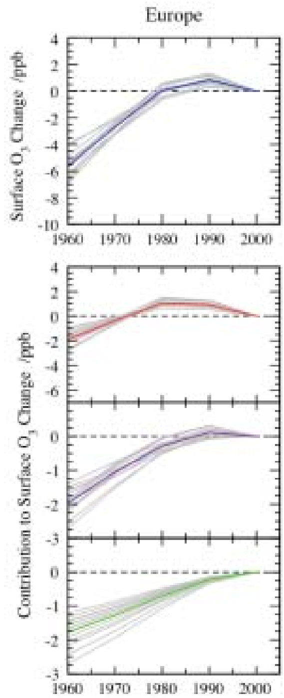


Figure A19: Calculated Ozone trends in Europe for 1960-2000 (a) and the contributions from an ensemble of models from European sources –red (b), non-European sources -blue (c) and methane –green (d). Taken from Wild et al. (2012).

A5. Persistent pollutants

After significant emission reductions of HM and POP before 2005, Little improvements have been noted since then. Pollution levels are still a concern.

Heavy Metals (HMs) and Persistent Organic Pollutants (POPs) differ in several respects to the classical air pollutants in terms of sources, long-range atmospheric transport behavior and regulatory context. HMs and POPs are known for their toxicity and have adverse effects on human health and the environment (carcinogenicity, mutagenicity, reproduction toxicity, endocrine disruption, etc.[3]). HMs are elements which are naturally present in the environment. Their levels in ecosystems have been significantly enriched compared to pre-industrial time because of anthropogenic activity. POPs are either intentionally produced chemicals (e.g. pesticides, industrial chemicals) or/and unintentional by-products, often from combustion (e.g. polyaromatic hydrocarbons - PAHs, dioxins and furans – PCDD/Fs). POPs accumulate along food chains and in individuals: low environmental concentrations can lead to significant exposures over time. Many POPs furthermore undergo reversible atmospheric deposition, and uncertainties therefore remain whether contemporary atmospheric burdens reflect "fresh" primary emissions amenable to further control strategies - or secondary emissions from contaminated reservoirs as polluted in the past.

Anthropogenic emissions of heavy metals and some POPs were significantly reduced in the EMEP countries over the last two decades. Emissions of heavy metals declined from 60% (mercury) to 90% (lead). POPs emissions decreased from 40% (PAHs) to 85% (PCB and HCB). Many POPs and POP-like substances that are not covered by the convention are not monitored regularly and the overall emissions of persistent chemicals are likely increasing or remain unchanged.*Source categories*

Decrease of emissions and consequent decline of pollution levels of HMs and B[a]P is achieved due to reduction of emissions from particular emission source categories. Prevailing contribution of road transport for lead and metal production for cadmium in 1990 was replaced by industrial and non-industrial combustion in 2010. Changes in sectoral composition of mercury and B[a]P emissions were less significant. Nowadays, the prevailing sectors in deposition of all three metals include industrial combustion, non-industrial combustion, metal production and energy production (Figure A20). For B[a]P major contribution originates from residential heating and industry-related sources.

[3] REACH data, http://scorecard.goodguide.com, www.echemportal.org, and others

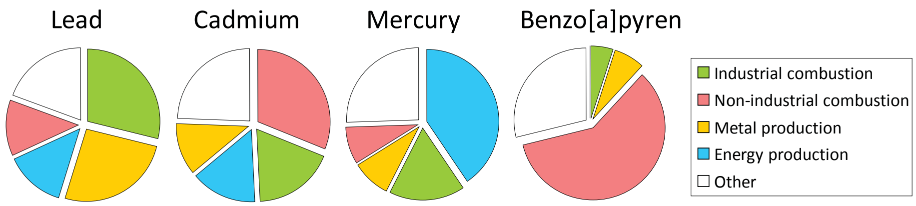


Figure A20: Relative contribution of the key source categories to pollution levels of lead (a), cadmium (b), mercury (c) and B[a]P (d) in the EMEP countries in 2010.

Pollution reduction

The reduction of emissions (primary and secondary) has led to decline of pollution levels in the EMEP countries. HM levels declined from 75% (lead) to about 35% (mercury) (Figure A21). (Legacy) POP level (as far as monitored under CLRTAP) decline ranged from 90% (HCB) to 40% (B[a]P). The rate of the decline was not uniform and differed among the considered pollutants. Lead and HCB levels had been rapidly decreasing in the beginning of 1990-s, and since 2000 the rate of the decrease slowed. Mercury and cadmium levels have been declining almost uniformly from 1990 to nowadays. B[a]P and PCDD/Fs levels are characterized by fast reduction in 1990-2000, replaced by some growth in present time.

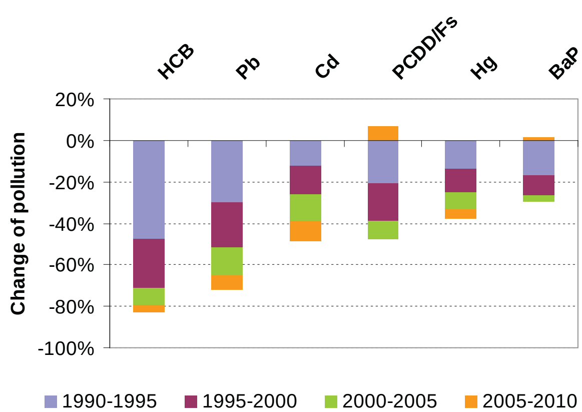


Figure A21: Relative reduction of HM and POP pollution levels over the period 1990-2010 in the EMEP region

Long-term changes of the levels assessed by modeling are generally confirmed by available data from EMEP monitoring network. Besides, similar reduction rates of HM levels are demonstrated by results of biomonitoring of HM concentrations in mosses.

Because of relevant long-term monitoring efforts under CLRTAP, we now have a far better understanding of the temporal and spatial distribution of both HMs and many POPs than in the past. However, long-term temporal trends often varies across sites and pollutants as illustrated for POPs (Figure A22). Some organochlorine pesticides now banned for an extended time period show a sharp decline (Fig A22a), whilst for other POPs no trend could be observed for many sites (Fig A22b). Even within groups of similar POPs like the PCBs, differences in time trends could be notable (Fig A22c,d).

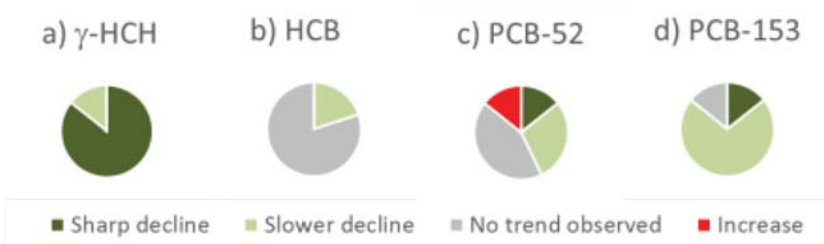


Figure A22:. Lumped long-term time trends in concentrations of selected POPs in air from selected EMEP sites. Data represent up to 7 sites and up to two decades of monitoring (for details, see WEOG 2015).

The reductions in heavy metal emissions within Europe have been extensive, and the observation data clearly reflect these changes. All the EMEP sites with long term measurements since 1990 show significant reductions in concentrations for lead (up to 90%) and cadmium (up to 70%). For mercury the observed levels decreased significantly up to the end of the nineties and leveled off the last decades (Tørseth et al, 2012).

EECCA vs EU

Reduction of pollution levels strongly varies among the EMEP countries. While in the EU-28 countries the reduction is much stronger than EMEP-average value, in the EECCA countries it is relatively low. The highest total reduction of pollution levels was noted for EU28 countries. On average, it occurred to be more than 80% for lead, 60% for cadmium, 35% for mercury and 41% for B[a]P. (Figure A23). In the EECCA countries the decline of the pollution levels is smaller: total reduction for 1990-2012 amounted to 76% (lead), 49% (cadmium), 19% (mercury) and 3.6% (B[a]P). Both within EECCA and EU28 groups the range of total reduction among countries is large. In some countries the total reduction of cadmium and mercury is even negative, which means that pollution levels tend to increase in long-term perspective. In case of B[a]P, the long-term increase of pollution levels takes place for almost 60% of the EECCA countries and for about 20% of the EU28 countries.

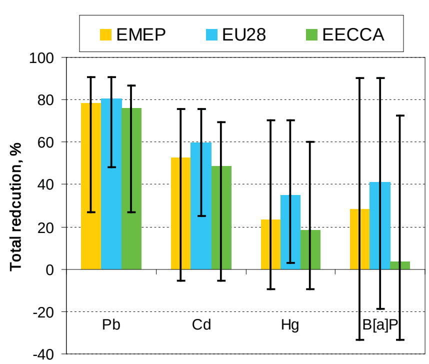


Figure A23: Total reduction of lead, cadmium and mercury deposition and B[a]P air concentrations in the EMEP region as a whole, in EU28 and in EECCA countries. Whiskers indicate range of the reductions among the countries. Negative values of the reductions mean increase.

Transboundary transport and secondary sources

In spite of HM and POPs pollution reduction in the EMEP region transboundary transport continues to play an important role. Change in the emission pattern led to redistribution of transboundary fluxes between the EMEP countries. Contribution of foreign sources to anthropogenic deposition has changed substantially in some countries but still remains significant in most of them.

HM and POP pollution levels are influenced by anthropogenic emissions, secondary sources in the EMEP region and intercontinental transport. For lead and cadmium the decline of pollution levels is smaller than the reduction of anthropogenic emissions because of effect of secondary emissions which long-term changes are relatively small. Mercury levels are strongly affected by emission sources located outside the EMEP region. Decline of HCB, PCB and PCDD/Fs levels considerably depends on long-term changes of secondary emissions. The decline of these POPs is mainly linked with strong regulation in ECE on major stationary sources. If these regulations would not continue things could get much worse.

Available model estimates indicate that intercontinental transport of Hg as well as PCDD/Fs, HCB, and PCBs can substantially contribute to pollution of the EMEP countries (from 20 to 70%, Figure A24). In particular, Hg deposition on average consists of almost equal contributions of contemporary anthropogenic emissions and emissions from secondary sources (Figure A25). A half of the anthropogenic part is contributed by domestic emission sources and the other half is by transport from sources located in other regions. The largest external contributors include East Asia (11%), Africa (4%), Southeast Asia (2%) and South America (2%). Similar or even larger contribution of secondary sources (re-emission) is characteristics of HCB and PCBs, which are cycling between the atmosphere and other environmental compartments for decades.

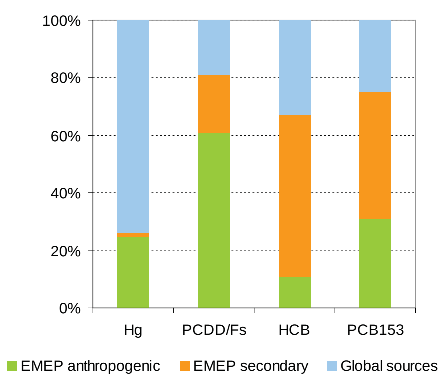


Figure A24: Relative contribution of different source types to contamination of the EMEP countries with Hg and some POPs. Global sources include both anthropogenic and secondary emissions

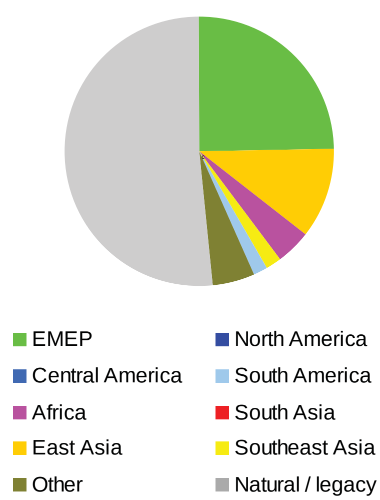


Figure A25: Source attribution of average mercury deposition to the EMEP countries

Effects

For both heavy metals and POPs, human and ecosystem exposures occur via a number of pathways and atmospheric emissions and long range transport contribute in varying degrees to the exposure either directly or indirectly (e.g. via uptake in food chains in remote areas). Science-based policies aimed at reducing exposure need to consider all relevant exposure pathways. Given the increasing epidemiological evidence of low-dose effects, the present concepts of thresholds or safe exposure levels are not sufficient.

Decline of pollution levels for 1990-2010 period resulted to improvement of the environmental conditions from viewpoint of negative effects on human health and biota. However, human health and the environment continue to be at risk in many EMEP countries despite important reductions of HMs and POPs. In a number of countries critical loads of lead and mercury are still exceeded (Figure A26). High deposition levels of cadmium still remain in a number of 'hot spots' close to industrial regions.

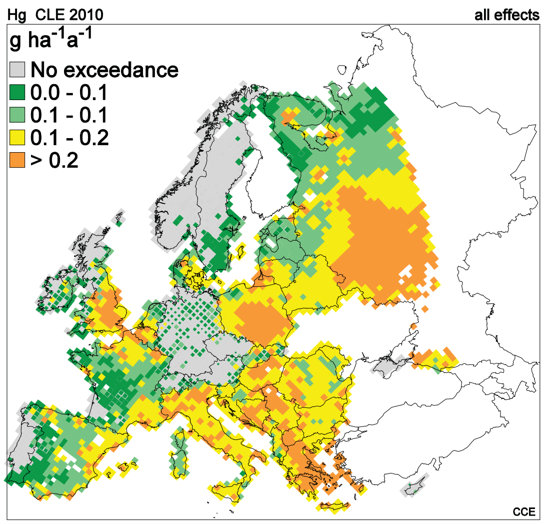


Figure A26: Computed critical load exceedance of mercury in 2010 assuming implementation of current legislation. Areas where mercury accumulation in soils and ecosystems may be highest are shaded in orange (Adapted from: Hettelingh et al, 2015)

Although number of people exposed to B[a]P concentrations above EU target value of 1 ng/m^3 (Directive 2008/50 EC) substantially (around 6 times) decreased from 1990 to nowadays, it is still significant (about 16 million). The number of people living in these areas in selected UNECE countries is shown in Figure A27.

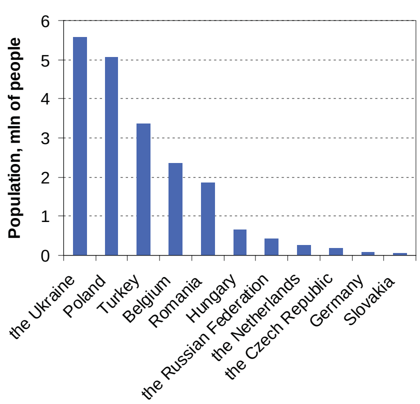


Figure A27: Number of people living in regions where B[a]P air concentrations exceed EU target value of 1 ng/m^3 in EMEP countries in 2012.

Hemispheric and global cycling of mercury and some POPs is an important aspect when discussing policy actions to reduce environmental concentrations and human exposure of these contaminants. The UNECE region is thus affected by emissions from other parts of the globe and emissions occurring within the region consequently contribute to deposition in other areas. The capability to quantify the inter-continental transport is thus an important part of the development of international agreements. This global aspect has also been the foundation for the Stockholm Convention on POPs and the Minamata Convention on Hg.

The geo-atmospheric cycling of mercury and POPs includes not only atmospheric transport and transformations but also interactions with the earth´s surface with deposition processes as well as re-emissions are important factors in determining the fate of these contaminants. Marine transport, biological transport as well as international transport in goods and (e-) waste is part of the global cycle.

Re-emissions from environmental media such as land, vegetation and water surfaces is partly driven by concentrations in the surface media and processes occurring in these media that can lead to transformations or retention. This places large challenges on model development where a multi-compartment approach is often required to represent the environmental behaviour and fate. The multi-compartment aspects are especially important when modelling inter-continental transport where interactions with land and oceans are of importance.

Remaining issues

The concern for health effects caused by HM and POP warrants further policy action to reduce atmospheric emissions and long-range transport. Since a significant proportion of the deposition in many regions have hemispheric or global origin, effective policies would need to take these geographical scales into account. Improvement of emission data, knowledge about remaining abatement options as well as improved monitoring and modelling of the fate of pollutants through air, water, soil and biomass would be useful for effective future agreements.

B. What are key challenges and opportunities?

B1. Air pollution measures could improve the economy

With current policies exposure to fine particles in the EU are projected to decrease by% between 2005 and 2030, Technically a further..% reduction is possible. The costs of such an effort will be €..bn (or ..% of the total costs of current policies). The damage to health would be reduced by ..%. Almost 70% of this reduction (..%-points) can be obtained at 10% of the costs. Such a policy strategy would be optimal as the marginal costs would equal the marginal benefits (when taking the lower range of the uncertainty margin of health benefit estimates). (See COM 2013 (Impact Assessment), IIASA 2013 (EC4MACS final report)).

The costs of air pollution abatement can be reduced substantially (..%) with implementation of a successful climate and energy policy, e.g. energy saving and replacing fossil fuels with renewable energy (IIASA 2014 (EP-report). Moreover air pollution abatement costs are estimated conservatively: technological changes (e.g. fast implementation of electric vehicles) have not been taken into account. The average costs of an optimal air pollution strategy would be ..-..% of GDP, although these percentages would be larger in countries with a low GDP. Financial and technological assistance could help to reduce the cost burden for EECCA countries, including assistance in increasing the energy efficiency of EECCA-economies (e.g. less leakage of gas) and a gradual switch towards a low carbon economy.

The GEM-E3 model (JRC) shows that the macro economic impacts of additional air pollution measures are close to zero (COM 2013 (Impact Assessment)). Comparable results were found for additional climate and energy measures. One of the reasons is that such measures would increase costs in some sectors (e.g. the energy sector or agriculture), but at the same time create jobs in other sectors (e.g. the construction sector or metal industry). Air pollution measures could increase the production cost in exporting sectors and lead to a loss of competitiveness and jobs. These effects will be considerably less when the geographical coverage of the international agreement to reduce air pollution is larger. Investments in abatement measures could decrease investments in production capacity, but would also lead to less waste of energy or materials and a higher efficiency of production processes. Cleaner air would mean a healthier work force and less absence from work. This could lead to lower labour costs increase the competiveness of the economy.

Air pollution policy has winners and losers. It is understandable that the fossil fuel energy sector and (industrial) farmers are critical about air pollution policy plans, but from a welfare economic point of view the societal benefits are almost always substantially higher than the costs some sectors have to make.

B2. Transboundary and multisectoral approaches

The atmospheric emissions of most of pollutants have decreased significantly in the UNECE region over the two last decades. Ambient air concentrations have decreased as well, but not with the same slope, and it can even be disappointing for stakeholders that their efforts for reducing emissions are not so visible considering population or ecosystem exposure. The key point is that air pollution concentrations and deposition are results of multiple factors. Among them, transport and chemistry influence the impact of air pollution sources over large domains and this is the reason why the relevant scale for air pollution control often needs to go far beyond the exposed and affected areas. An effective transboundary approach would even have to go beyond the current UNECE region to tackle many of the most important air pollution issues in order to achieve significant improvements and meet long term objectives.

The use of fossil fuels and biomass for electricity production, heating and transport, as well as the nitrogen losses from agriculture continue to be the main causes of air pollution and the associated risks for human health and ecosystems.

Emissions of several air pollutants, especially SO_2, NO_x, NMVOC and particulate matter could benefit from international climate and energy policies aiming to reduce the use of fossil fuels.

Ammonia emissions from agriculture however would not profit from such climate policies and remain to require attention from air quality managers. The transboundary component of air pollution will remain to be important: secondary inorganic particles (ammonium sulfate and ammonium nitrate) form an important part of the transboundary fluxes of particulate matter and contribute significantly to the exposure of the population in several European cities (see figure B1 left panel). Moreover the use of biomass and coal for residential heating forms an important source in several cities (see figure B1, right panel).

Effective reductions of PM2.5 levels to meet the WHO annual guideline value of 10µg/m^3 cannot be achieved by isolated local measures, but need to involve multiple economic sectors, and must be internationally coordinated. Remaining hot spots areas, especially in large cities or cities where local meteorology and site characteristics contribute to high PM levels can to a large extend be managed with additional local control measures, but betting on local policies alone to deal with PM exposure in the cities can lead to inefficient and disappointing results.

Source apportionment studies demonstrated the large influence of long range transboundary transport to PM patterns in Europe. Figure B1 illustrates clearly the influence of transboundary and national contributions in PM2.5 concentrations in Dutch and German cities, and the little improvement that can be expected from local control policies alone. Of course, international/local ratios differ across Europe (e.g see the Polish case) depending on the location of the city, the industrial profile and the technologies implemented by the country, but a significant part of the measures to reduce PM exposure in cities must in most cases be the result of international or national strategies.

Netherlands **Germany** **Poland**

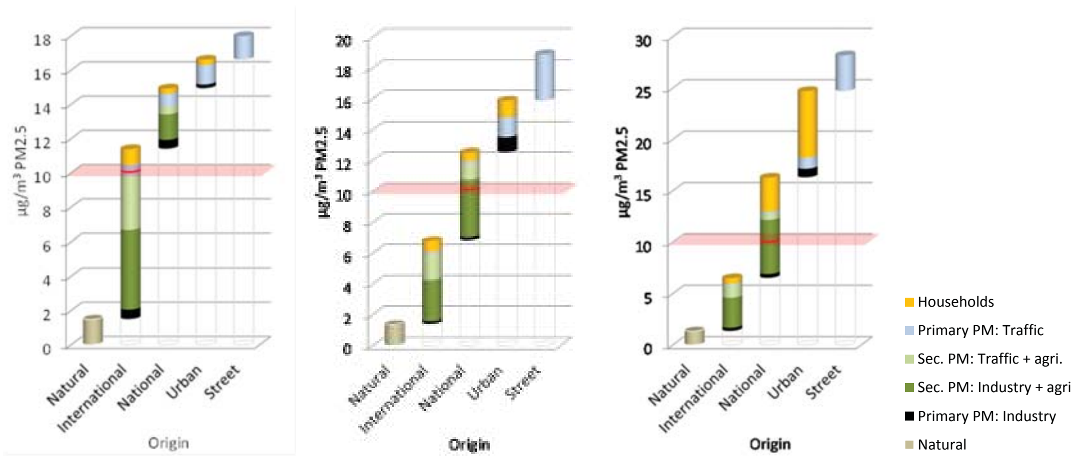


Figure B1: Sectoral contributions to PM2.5 exposure in cities in the Netherlands, Germany and Poland, 2009. Source: Kiesewetter et al., ACP, 2015

The Protocols of the LRTAP Convention provide a prime example for effective strategies that involve emissions of multiple substances emitted from a wide range of economic sectors. This experience also points the way forward towards achieving the WHO guideline values throughout Europe in the most cost-effective way.

However, while in the past, controls involved mainly emissions from the power sector, industry and transport sources, for further air quality improvements the focus must necessarily shift towards small stationary combustion sources, especially in the residential and commercial sector, and to agriculture.

Although additional emission controls will involve additional costs, the tools developed under LRTAP can identify cost-effective portfolios of measures in different sectors that achieve the envisaged health improvements at least cost. Such analyses takes into account that in many sectors significant emission reductions have already been implemented, and that further cuts will be costly. They also consider that in other sectors additional measures, although cost-effective from a social planner's perspective, might put unproportioned burdens to certain groups of the society or economic sectors.

As mentioned above, NH_3 emissions from agriculture emerge as a key focus for further measures. All analyses indicate a strong need for substantial reductions of NH_3 emissions in Europe, both for approaching the WHO guideline values for PM2.5, to which secondary inorganic aerosols (i.e., NH_4SO_2 and NH_4NH_3) whose formation is strongly steered by the availability of NH_3 in the atmosphere) and for preserving biodiversity of ecosystems, which is threatened by excess nitrogen deposition.

The WHO review of the health effects of air pollution (REVIHAAP) has clearly established total PM2.5 mass concentrations (including secondary inorganic aerosols) as the most health-relevant particle metric (check for exact wording), and the WHO guideline value for fine particulate matter is defined in terms of PM2.5 mass concentrations. As the formation of secondary inorganic aerosols is steered by the abundance of NH_3 in large areas of Europe (REF EEA report), controls of NH_3 emissions emerge as the logical requirement for an effective reduction of health effects. However, as also pointed out by the WHO-report, it cannot be ruled out that the potency of health effects is different for different components of PM. (check for wording).

This uncertainty might have important consequences for the relative importance of NH_3 emission reductions compared to other PM precursor emissions, if a policy is solely targeted at reducing health impacts. However, as practiced for the multi-pollutant/multi-effect Protocols of the Convention, a multi-effect perspective that addresses health impacts in conjunction with, e.g., biodiversity concerns, offers a robust risk management approach thathedges against the uncertainty of the health impacts of secondary inorganic aerosols. If these aerosols would not be linked to negative health effects, NH_3 reductions will be still warranted for the protection of biodiversity.

Secondary particles

PM concentrations result from both primary PM emissions and the formation in the atmosphere from complex chemical processes involving many organic and inorganic precursors. New and better methods for measurements of PM composition that have been developed over the last 10 years now (ref EMEP IOP) allow better qualification of the relative contributions from primary emissions which may be controlled locally, and secondary aerosols. The secondary aerosols result from complex chemical processes that involve organic and inorganic species and develop over large geographical areas. More or less all significant air pollution sources are of importance for the secondary aerosol formation: biomass burning and residential heating, road and off-road traffic, industry, agriculture. Inorganic aerosol formation processes (that lead for instance to ammonium nitrate or ammonium sulfate) are generally better known than organic aerosols that involve a large number of partly unknown chemical species (ref).

Huge PM spring episodes that still occur in Western Europe are acknowledged to be mainly influenced by agricultural practices (manure and fertilizers spreading) which are responsible for large ammonia emissions in favorable meteorological conditions. Several results (Bessagnet et al + EEA report) show that a significant decrease in the PM peaks can only be achieved through concerted actions in several countries.

The influence of residential heating and wood burning to transboundary and national PM is also high but more difficult to assess because of uncertainties in emission inventories (including practices in various countries). In the UNECE region, a large panel of practices and technologies makes concerted management more challenging than controlling large combustion plants or road transport. Nevertheless coordinated action could to significant results.

B3. Air pollution at a wider scale

Air pollution related to ozone and some of its precursors, or to mercury and persistent organic pollutants such as PCDD/Fs, PCBs and HCB, is significantly influenced by sources around the world. The first steps to share knowledge at a wider geographical scale and define potential cost-effective measures have been taken both by the Task Force on Hemispheric Transport of Air Pollutants of the Convention of Long-Range Transboundary Air Pollution (TF HTAP) and UNEP's Climate and Clean Air Coalition (CCAC). Knowledge and experience from the CLRTAP is being shared with global Conventions on Mercury and Persistent Organic Pollutants.

The hemispheric scale of ozone pollution

Tackling the damage from long-term ozone exposure to public health, crops and forest growth in Europe effectively would require a Northern Hemisphere abatement strategy. Although peak concentrations of ozone have declined in parts of Europe, the background concentrations in some major regions of the Northern Hemisphere, such as Asia and the west coast of North America, show an increasing trend (see section A3). While peak ozone concentrations are largely determined by local emissions of NO_x and VOCs, on hemispheric to global scales ozone concentrations are also determined by emissions of the long-lived greenhouse gas methane (CH_4) and carbon monoxide (CO), as well as by natural variability of biogenic emissions and transport of stratospheric ozone into the troposphere. Together, NO_x, VOCs, CO and CH_4 interact to form ozone, changing the oxidation capacity of the troposphere (governed by the reactive OH radical) and forming long-lived reservoir species such as peroxyacetyl nitrate (PAN).

Global ozone precursor emission changes between 1990-2010

While the emissions of ozone precursor gases NO_x, VOC, and CO have declined by more than 40 % from 1990-2013 in Europe (EMEP, 2015), and similar reductions have been achieved in North America, emissions have increased by 20-30 % in the rest of the world, and by as much as 50 % in emerging economies like China and India (Figure 1). Global anthropogenic emissions of CH_4 were stable in the 1990s, but increased in the 2000s (Figure 1 and 2). Due to its 10-year lifetime and uniform global distribution, the global abundance of methane can be determined accurately. Methane observations from the global NOAA network show strong increases until 1998, followed by a decade of near-stagnation, and have been growing again since 2008. A strong inter-annual variability of natural sources and sinks, but an underlying long-term trend that is driven by anthropogenic emissions are consistent with these observations.

HTAP ozone scenarios between 2010-2050

How will future ozone respond to changes in anthropogenic emissions in Europe, North America, and the rest of the world? And what is the role of CH_4 relative to CO, VOC and NOx emissions? To assess this, the GAINS model (Amann et al., 2011) was used to generate a set of emissions under a range of assumptions about air pollution and climate policies.

The HTAP (ECLIPSE V5a) Current Legislation (CLE) and Maximum Technically Feasible Reduction (MTFR) scenarios both use business-as-usual projections from the Energy Technology Projections study by the International Energy Agency (IEA, 2012) and Food and Agricultural Organization (FAO) projections of livestock (Alexandratos and Bruinsma, 2012). The IEA projections are similar to the RCP 6.0 scenario (until 2050) used by IPCC AR5 (van Vuuren et al., 2011) with regard to global fossil fuel CO_2 emissions. The Ref-MTFR scenario, developed for the time slices 2030 and 2050, shows the implications for emissions of implementing all currently existing technology options to mitigate air pollution and methane emissions, irrespective of their costs. This hypothetical scenario illustrates the full scope of emission reductions when known and proven measures are unconditionally implemented and enforced.

An additional energy-climate scenario (Clim-CLE) provides a perspective on the potential of changes in the energy system to reduce air pollutants and methane emissions. Clim-CLE draws on the IEA "2 degrees" energy projections, which target 450 ppm CO_2 concentrations (IEA, 2012) through energy efficiency improvements, lower coal use, etc. Assumptions on air pollution legislation were adopted from Ref-CLE. The CO_2 emission trajectory is comparable to the RCP 2.6 pathway used in the IPCC AR5 report. In contrast to the scenarios developed by a number of global integrated assessment models, the GAINS reference (Ref-CLE) and climate (Clim-CLE) scenarios do not assume 'automatic' reduction of air pollution emissions with progressive economic development (Amann et al., 2013). Therefore, for NOx, NMVOC and CO some rebound effects are evident after 2030 (Figure B2), while CH_4 emissions are nearly constant in Clim-CLE (Figure B3).

Compared to earlier estimates (Amann et al. 2013), the global emissions in Figure 1 show a stabilization or slight decline after 2010 owing to recent control efforts in China (12th Year Plan and Action Plan, e.g., Zhao et al., 2013; Wang et al., 2014; Klimont et al., in preparation, 2015) (Figure B2), and assume effective enforcement of existing legislation. At the same time further strong growth of ozone precursor emissions is expected in several other regions (Figure B2).

The contribution of Europe and North America to global air pollutant and methane emissions is declining over time. While Europe contributed 30 %, 23 %, 16%, and 19 % of global NOx, VOC, CO, and CH_4 emissions in 1990, these fractions decline to 9 %, 10 %, 7 %, and 9 % for Ref-CLE in 2050, with similar fractions for the other scenarios. Similar declining contributions are seen for North America, except for methane. In contrast, the contributions of East Asia, South Asia, and the rest of the world are increasing, reaching about 80 % of global emissions for all scenarios by 2050. There is a huge potential for methane emission reductions in the waste and fossil fuel production sectors (Ref-MTFR and Clim-CLE, Figure B3), while emissions from the agricultural sector are more difficult to reduce. The growth of CH_4 emissions takes places mainly outside of the UNECE domain.

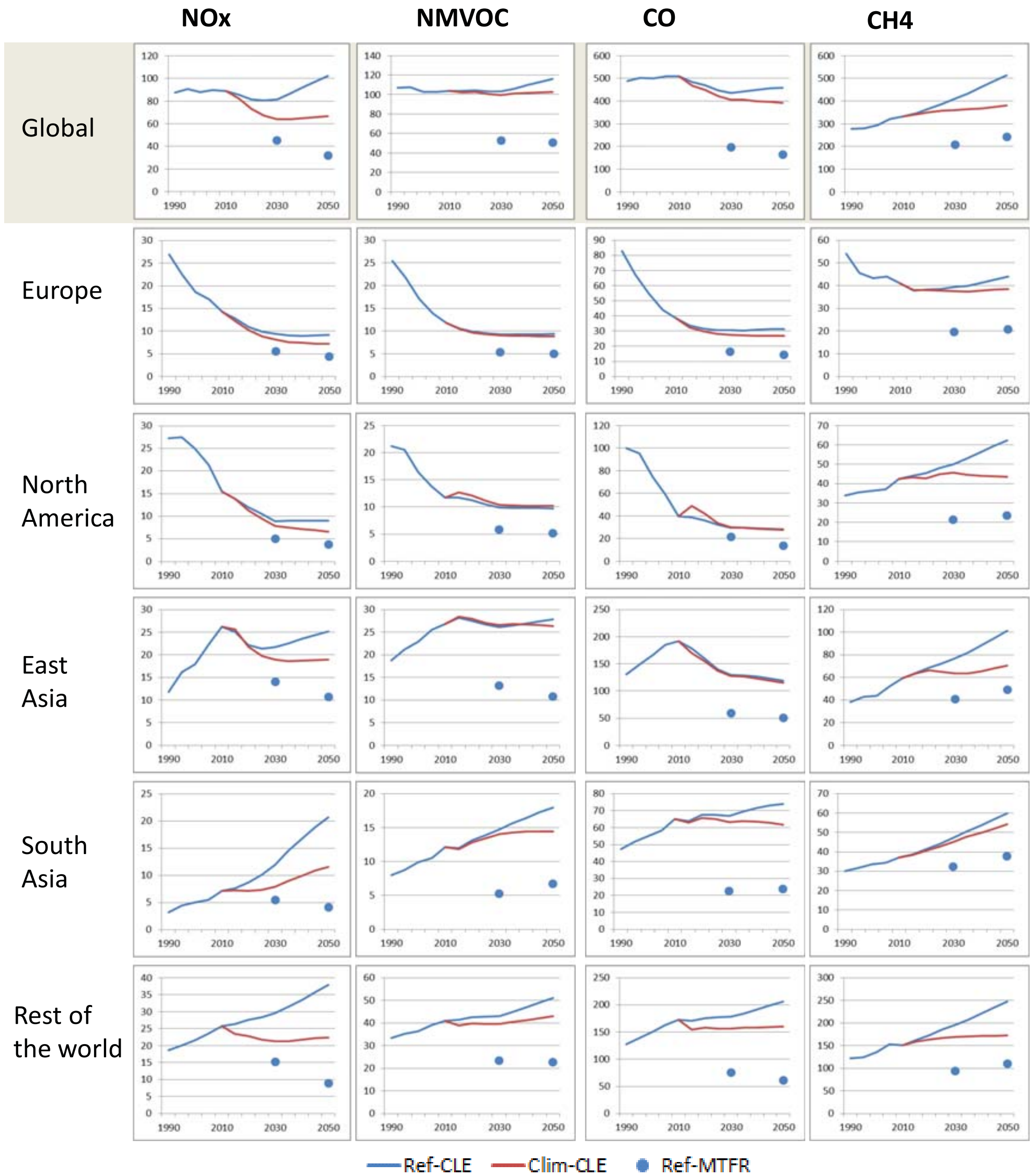


Figure B2: Trends in the anthropogenic emissions [Tg] of NO_x (as NO_2), NMVOC, CO and CH_4 for the world and five major regions, and the Ref-CLE, Clim-CLE and Ref-MTFR scenarios. The first scenario year is 2015.

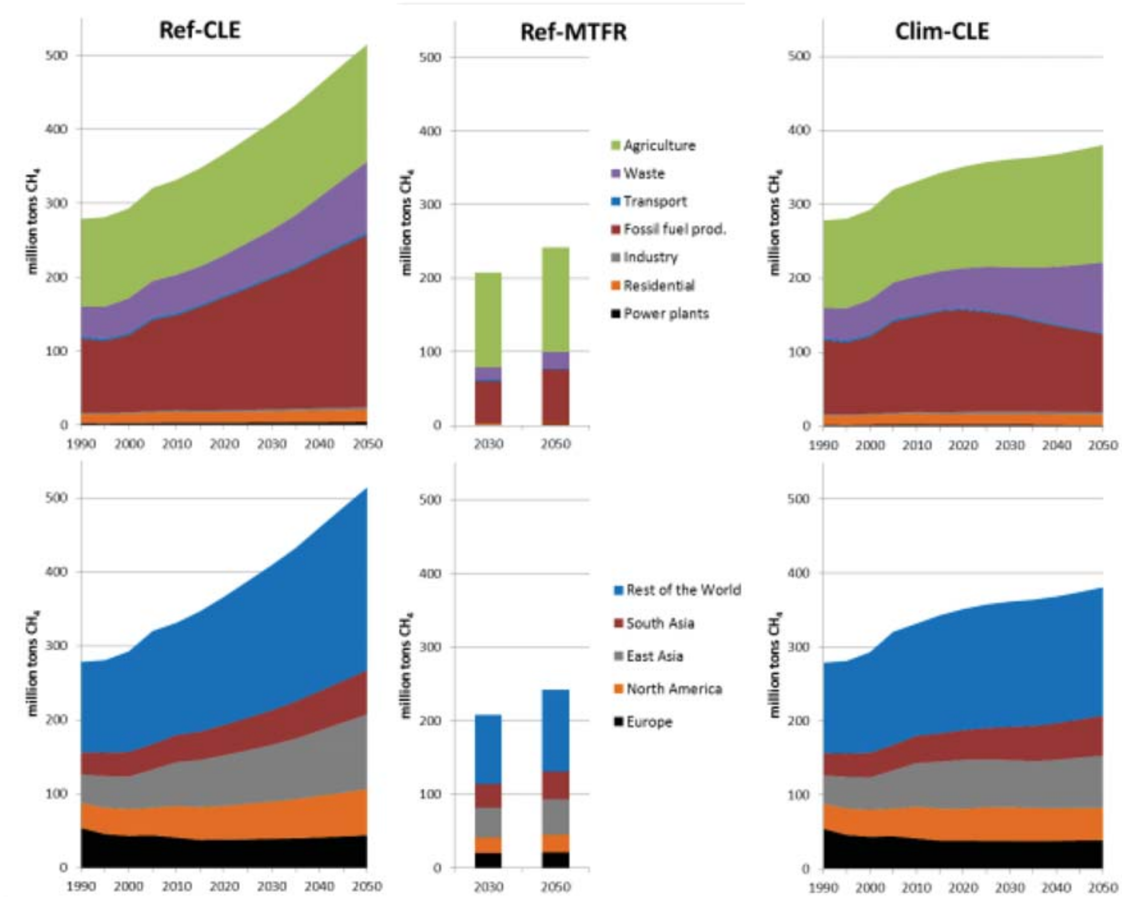


Figure B3: HTAP (ECLIPSE V5a) CH_4 emission scenarios; Baseline (Ref-CLE and Ref-MTFR) and climate scenario (Clim-CLE). 1 million ton is 1 Tg.

The HTAP simulations indicate that, after an initial decrease in region-wide annual average ozone in North America and Europe, ozone may start increasing again after 2020-2030, progressively driven by methane. Further ambitious pollution controls (MTFR) could drive down annual ozone in Europe by up to 4 ppb by 2030 and 7 ppb by 2050, with approximately equal contributions from controls outside Europe and methane emission controls, and a smaller contribution from controls in Europe. Although there is a significant model spread underlying these calculations, the difference between scenarios is generally larger than the spread. Ozone in summer, relevant for the growing season, declines more strongly than in winter, and stabilizes at about -3 ppb for the Ref-CLE scenario, but returns to 2015 levels by 2050. The Ref-MTFR scenario, which also includes a number of progressive CH_4 emission reductions, reduces summer ozone by 8-9 ppb.

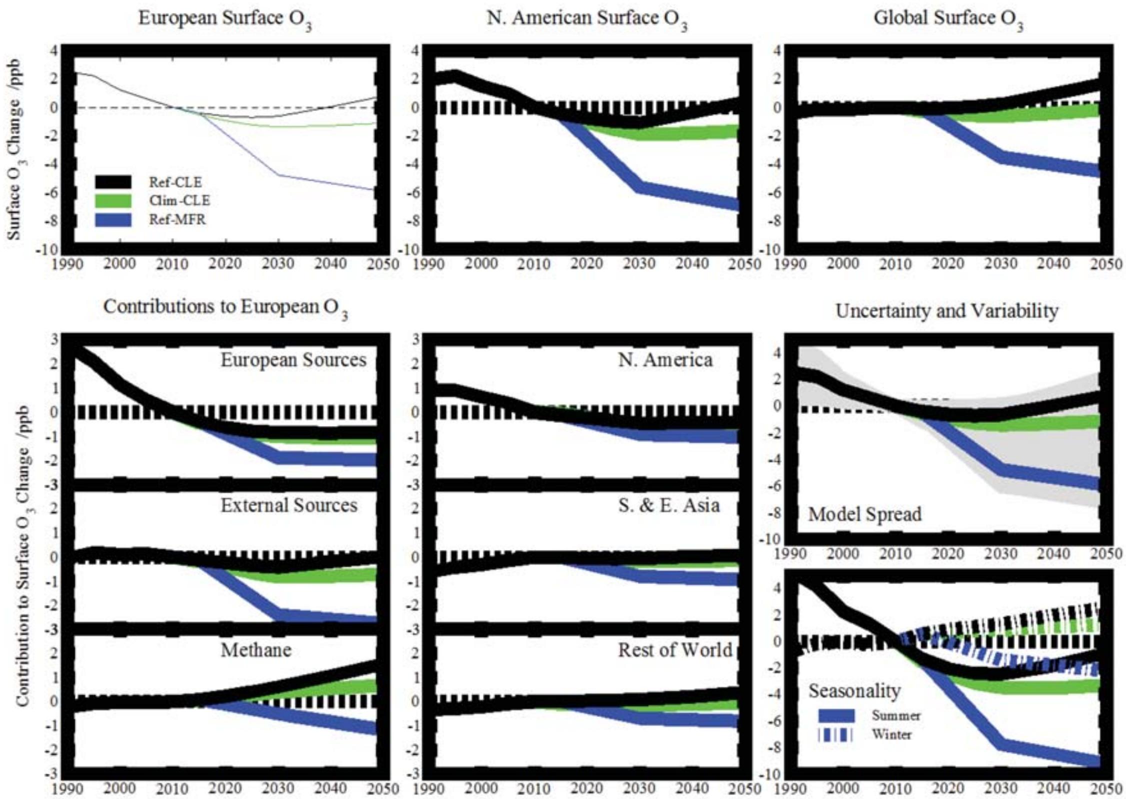


Figure B4: HTAP analysis of future annual surface ozone changes in Europe, North America and the world, and the contributions to ozone in Europe from European, North American, Asian, and Rest-of-the-world sources of NOx, CO and VOCs, and from global CH_4 emissions. Right-hand panels show model uncertainty and seasonal responses in summer (JJA) and winter (DJF). Emissions from ECLIPSEv5a database (Klimont et al., manuscript in preparation, 2015), and ozone from HTAP simulations described in Wild et al. (2012).

The TF HTAP analysis shows that in future, ozone in Europe will become increasingly dependent on the development of emissions in other parts of the world. For the CLE case, ozone reductions due to European policies are largely annulled by increases in ozone from methane and by emissions outside Europe. Effective implementation of air pollution policies in emerging economies will lower the hemispheric ozone concentrations arriving in North America and Europe. Methane, an important greenhouse gas, is included in the basket of emissions included in the Kyoto protocol. Methane is not only important for climate, but also increasingly for reducing impacts on health and vegetation, and needs consideration in its own right. The LRTAP Convention could therefore consider ways to include methane emission reductions in future negotiations and agreements.

Mercury's global reach

Mercury is emitted from both anthropogenic as well as natural sources, and due to its long residence time can be transported across the world. The Minimata Convention on Mercury is a treaty to protect human health and the environment against the adverse effects of Hg. Methods and technical analysis by the TF HTAP have contributed to a better understanding of the benefits for regions and countries of global cooperation, and options to further reduce mercury. Figure B4b displays the development of deposition in 2035 aggregated over six world regions for three future scenarios.

By 2035 currently decided policies will lead to a decrease of Hg deposition by 25 % in North America and Europe, mainly due to internal policies. In this scenario, Europe's own contribution to Hg deposition declines from ca. 75% to 50 %. In Africa, deposition will roughly stabilize, reflecting declining long-range contributions and increasing African sources. Deposition increases by ca. 20 % in East Asia, and by a staggering 100 % in South Asia. New climate Policies (NP) are beneficial for all continents, but in particular for East Asia, related to declining reliance on coal-burning in China. Implementation of all available technologies to reduce Hg emissions has the potential to reduce Hg deposition by 75 % or more.

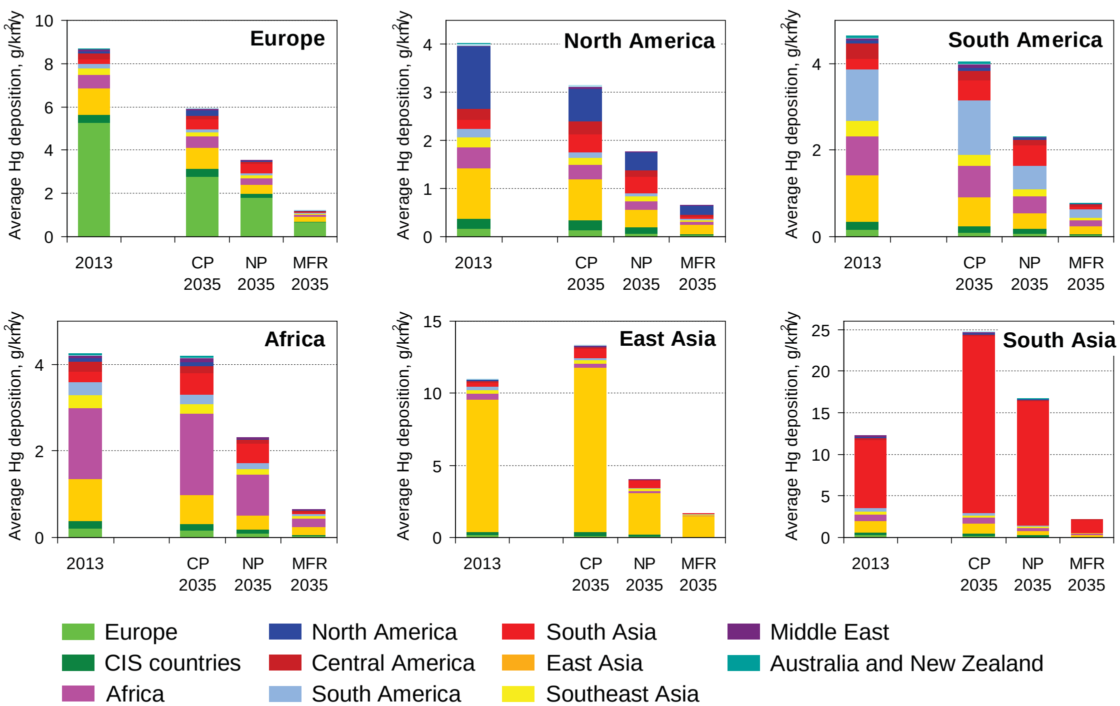


Figure B4b: Mean Hg deposition from direct anthropogenic sources calculated by an ensemble of global models for 3 emission scenarios. CP describes the situation when current policies and measures existing in 2010 are fully implemented (similar to CLE). NP New Policy describes (similar to CLIM) commitments to reduced GHG emissions, leading to further Hg reductions. MFR shows maximum feasible reductions that could be achieved with currently known technologies. Deposition due to legacy/natural emissions are not included. Work has been performed within the FP7 GMOS project (www.gmos.eu). Reference: Shatalov et al, 2015.

B4. Air quality and climate change: two sides of the same coin

Additional measures, if seen in isolation, are more costly, although benefits outweigh costs. In addition, they offer significant synergies (and potential trade-offs) with other policy priorities.

The necessity of further emission reductions across many economic sectors, including those that have not contributed substantially in the past, offers new opportunities for synergies with other policy priorities that could provide additional arguments for taking measures.

In particular, a wide body of scientific literature has highlighted numerous facets of physical and strategic interactions between air quality and climate change policies. Interactions occur along multiple pathways, and act in both directions.

Many of the air pollution controls have clear co-benefits on greenhouse gas emissions and climate change. To the extent air pollution controls increase energy efficiency and/or reduce consumption of fossil fuels, they will lead to concomitant cuts in CO_2 emissions. Although the traditional focus on end-of-pipe air pollutant controls has paid only little attention to this aspect in the past, there is a significant potential for such win-win measures in the future, and they become more economically competitive with increasing costs of emission controls (e.g., co-generation). Vice versa, some of the technical air pollution emission controls that have been employed in the past lead to (slightly) higher CO_2 emissions (e.g., flue gas desulfurization, denox), although in many case this increase is compensated by concomitant improvements of energy efficiency that emerges from better controlled process conditions.

Most of the air pollutants also affect climate during their (comparably short) residence time in the atmosphere, either enhancing or masking temperature increase. At present time, the climate forcing from the air pollutants is substantial (with a net cooling effect), and air pollution controls will alter the net balance. To limit the rate of temperature increase in the coming decades air pollution policies could focus more on the abatement of air pollutants that have a both a warming effect and impose risks to human health and ecosystems: black carbon and ozone precursors, including methane (Figure B5).

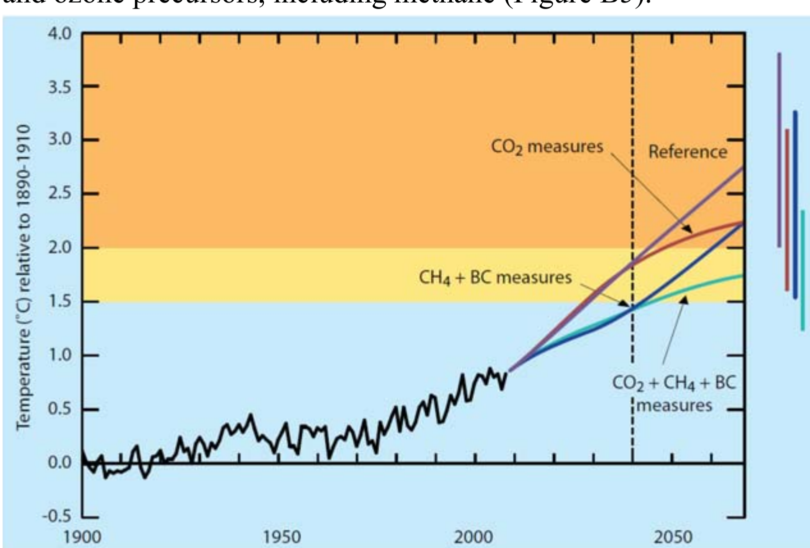


Figure B5: Role of Methane and Black Carbon reduction in climate policy. Together with aggressive CO_2-strategies they increase the probability to stay below the 2^o target (Source: UNEP/WMO, 2011)

Ozone formation is a good illustration of the positive feedbacks between climate change and air quality. Ozone itself would enhance warming. It would also reduce the uptake of CO_2 from the atmosphere by vegetation and forests and thus influence the development of CO_2-concentrations in the atmosphere. In turn a warmer climate could increase direct ozone formation and release more biogenic ozone precursors. Tackling ozone precursors would have positive effects for health, ecosystems and climate change mitigation.

On the other hand, climate policy will ‘automatically’ influence the emissions of air pollutants related to the use of fossil fuel. Reductions in fossil fuel use will not only reduce CO_2-emissions, but also reduce emissions of SO_2, NO_x, NMVOC, particulate matter and several heavy metals (such as mercury) and persistent organic pollutants (such as PAH, PCDD and HCB). This could either lead to an additional reduction of risks for human health and ecosystems, or to a reduction of costs to meet air quality standards. Such co-benefits for air pollution are dominating the benefit/cost ratio of climate measures.

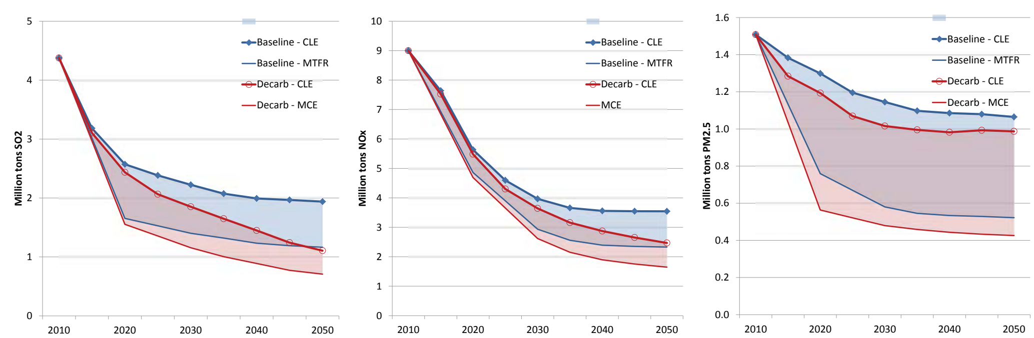


Figure B6: Scope for emission reductions for SO_2, NO_x and PM2.5 in the EU, with and without climate measures (to be updated with recent COP21 results)

However neither an ambitious climate change or air quality abatement policy will automatically yield benefits for each other without integrated policies aiming at co-beneficial solutions especially in the energy production and transport sector. The combination of an ambitious climate policy and maximum feasible air pollution emission reductions in these sectors is absolutely necessary to meet the WHO air quality guideline values in Europe as well as meeting a need for reduction of climate warming components.

Although for most climate measures would help to improve air quality, there is an exception for the use of biomass as a substitute for fossil fuels. Especially residential wood burning contributes to indoor and outdoor exposure to particulate matter and would reverse the positive health effects of air pollution policies. Increased use of diesel engines will potentially lower fuel consumption compared to gasoline engines. However their emissions of air pollutants require exhaust cleaning techniques that require energy and hence can increase fuel consumption and reduce the power produced. Even with these techniques their emissions of air pollutants, particularly NO_x, even at Euro 6 level are still higher than those of gasoline engines in real-world use. The air pollution consequences of different power production techniques and mixing with biofuels have to be carefully assessed.

Reducing emissions of CO_2 by exchange of fossil fuel with biomass in energy production might increase emissions of air pollutants as increased biomass production indirectly will affect land use and emissions of biogenic VOC.

Air quality and agriculture

Although climate policy includes limiting emissions of N_2O and methane from agriculture, NH_3 emissions will remain unaffected by climate policy. With the expected climate change NH_3 emissions from agriculture and natural sources even tend to increase (ref). This would pose additional risks for human health (via the formation of secondary inorganic aerosols) and for ecosystems (via excess deposition of nitrogen).

Besides the NH_3 and N_2O emissions to air, nitrogen losses during food production take place in the form of nitrate leaching to groundwater and runoff to surface waters. Environmental policy limitations on losses of NH_3, N_2O and NO_3 form a coherent framework to encourage a more efficient use of nitrogen in agriculture. Guidelines for good agricultural practices have been formulated within CLRTAP and could – if complied fully – reduce emissions of NH_3 by..%. Note that 80% of the NH_3-emissions in EU-countries are generated by less than 10% of the farms. The majority of the livestock is kept by a small number of industrial size farms. Ammonia abatement measures at such large farms would be much more cost-effective than measures at smaller farms.

Further steps could be considered to increase the nitrogen use efficiency including food consumption. This would require behavioural changes. Reduction of food waste, increased attention to food quality aspects and a shift towards low meat diets could offer significant additional NH_3-reductions and go hand in hand with encouraging healthy life styles.

Such changes would increase global food security and reduce the area needed to food production. This would offer opportunities for the protection of nature areas. There is however a potential conflict with increasing the use of biomass to substitute fossil fuels as a means to reduce CO_2-emissions. More biomass production could put additional pressure on agricultural land and nature areas.

Air pollution policy contributes to sustainable development targets Air pollution is linked to several sustainable development indicators. WHO has identified air pollution as one of the top10 causes of the global burden of disease. Air pollution policy can significantly contribute to the sustainable development target to promote healthy lives and well-being in the world. Abatement of air pollution also contributes to other sustainable development goals e.g. ‘access to sustainable and modern energy’; ‘safe and sustainable cities’; as well as to ‘protect terrestrial ecosystems’.

Air pollution policy contributes in several ways to the recently established Sustainable Development Goals of the UN:

- Improved air quality is the most effective environmental measure that can be taken to ensure healthy lives and wellbeing for all (SDG3). It is one of the elements to make cities and human settlements inclusive, safe, resilient and sustainable (SGD11).

- Nitrogen and ozone measures could help to promote sustainable agriculture, improve nitrogen use efficiency, increase food security and contribute to end hunger (SDG2). Such measures are also needed to protect, restore and promote sustainable use of terrestrial ecosystems, sustainable forest management, and halt biodiversity loss (SDG15).
- Substitution of polluting old power plants and residential heating by clean efficient technologies contributes to the target to ensure access to affordable, reliable, sustainable and modern energy for all (SDG 7).
- Air pollution measures contribute to a cleaner and more efficient agriculture, industry, power sector and transport system as part of the sustainable development targets to ensure sustainable consumption and production patterns (SDG 12) and to promote sustainable economic growth (SDG 8), industrialization and innovation (SDG 9).

Moreover as was shown before air pollution policies can strengthen actions to combat climate change and its impacts (SDG13).

B5. Institutional arrangements

Public health concerns currently dominate the air pollution policy agenda. Episodes with high levels of pollution raise public concern, cause health complaints and make air pollution literally visible. While such episodes raise public concern, the main burden of disease from air pollution is actually related to long-term, chronic exposure to air pollution, and not from occasional air pollution peaks. Several local initiatives have been taken to develop 'healthy' cities. Cities could learn from each other to choose the most effective options to reduce health risks. The Convention on Long Range Transboundary Air Pollution could choose to play a role in the exchange of knowledge and experiences between cities.

But cities cannot reduce the air pollution levels down to the WHO guideline levels on their own. Even during high pollution episodes the contribution of sources outside the city is often dominant. Local air pollution risks are still predominantly a transboundary phenomenon in many cities of Europe. Reduction of exposure to fine particles (PM2.5) would not only require reduction of emissions of particulate matter in cities (such as black carbon), but also of precursor emissions of secondary particles in a much wider area: sulphur dioxide, nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds. Collaboration and policy co-ordination within the EU and the Convention on Long-Range Transboundary Air Pollution remains important in defining the most cost-effective ways to reduce health risks due to air pollution and the divisions of efforts at the local, national and continental scale (see box).

Possible actions at different levels to move towards WHO-guideline values for PM2.5

At the continental level:

- Ensuring that vehicle emission standards work in reality
- Effective implementation of climate & energy targets
- Emission standards for non-road mobile machinery, domestic stoves and installations for biomass burning
- Ammonia emission standards for large cattle farms

At the national level:

- Ratifaction and implementaton of CLRTAP Protocols
- Effective control on maintenance schemes for vehicles
- Srapping schemes of old vehicles and motorcycles
- Implementation of climate and energy policies
- Enforcement of emission standards for farms and domestic stoves

At the local level:

- Low emission zones to encourage early scrapping of old vehicles
- Speed limits on highways near urban areas
- Stimulation of electric vehicles
- Improved infrastructure for public transport, cycling and walking (air pollution policy embedded in healthy city designs)

European wide emission reductions of these precursor emissions will be indispensable to meet the WHO annual guideline level for fine particles of 10µg/m^3. This would reduce the average loss of life expectancy in the EU with almost [6] months compared to the 2005 situation. Besides these health benefits, better nature protection due to reduced deposition of nitrogen would be a co-benefit.

In the Convention on Long-Range Transboundary Air Pollution long-term monitoring activities and developing the modelling capability have supported the issue framing and delivered robust data to derive salient policy information, in particular using risk quantification concepts and integrated assessment modelling to highlight the cause for action and the costs of inaction. The institutional setting provided by the Convention has been essential – also in building trust between different scientific fields as well as between science and policy. The flow of information is not unidirectional from science to policy: the explicit and implicit values expressed by national and international political processes find their way into the priority setting process for modelling and research, and the valuation of different, at times conflicting, policy targets (Voinov et al., 2014).

The success of the effect-based approach of the Convention is crucially dependent of the support from subsidiary scientific and technical bodies and it is important that these bodies continue to improve their efficiencies without losing focus on quality. The balance between a long term research agenda and a 'quick response' facility in the form of an integrated assessment model has proved to be an important element of the success of the Convention (Raes & Swart, Reis et al.2007).

The exchange of knowledge and experiences between scientific and technical bodies under the Convention and national experts is generally well organised. Dissemination of knowledge to national experts in EECCA-countries is currently being strengthened, with a focus on improving the quality of emission data and the assessment of health impacts of air pollution.

For some air pollution problems policy co-ordination at the European scale will not be sufficient: ozone, mercury and some POPs were mentioned above as pollutants that are transported at a hemispheric scale. This would require a co-ordinated policy that goes beyond the current domain of the LRTAP-Convention and would also include major polluters in Asia. Knowledge and experiences gained in the CLTRAP could be further shared with institutions working at a wider geographical scale, such as the IPCC, the CCAC, WHO, UNEP, WMO, the Arctic Council, the Minamata Convention or the Stockholm Convention.

A viable future of the Convention and its protocols depends on the positive and vigorous participation by the Parties in all parts of the region, and on ensuring its extensive geographical coverage. The capacity-building activities implemented by UNECE with support of several Parties to the Convention are aimed at improved ratification, implementation of and subsequent compliance with the key protocols to the Convention. A positive development in recent years is the increased involvement of countries in Eastern Europe, the Caucasus and

Central Asia. The support to these countries is provided both at the technical and policy levels.

Relevant efforts under CLRTAP have resulted in valuable infrastructures and form an important knowledge base for emission inventories, models, observations and impact assessments of pollutants. These results are unique and would not have been accomplished otherwise. The infrastructure not only ensures compliance under LRTAP, but also provide a valuable knowledge base available to support relevant efforts under global agreements, such as the Stockholm Convention on POPs, the Minamata Convention on mercury and the Coalition on Clean Air and Climate. Data and models developed under CLRTAP furthermore provide a valuable inputto many other regional programs and Conventions (e.g. the regional sea conventions HELCOM, OSPAR, and the Arctic Monitoring and Assessment Program under the Arctic Council).

Further work

Along with progress achieved in understanding the transport and fate of pollutants there are significant uncertainties associated with incomplete information on anthropogenic emission sources. These uncertainties can prove to be an important obstacle for EECCA countries to ratify the revised Gothenburg Protocol. Adoption of the emission limit values for new installations and vehicles is generally easier than the adoption of national emission ceilings or national emission reduction obligations, for countries where the national total emissions for the base year are incomplete or where it is unclear to what extend abatement technologies are already implemented. Agreement on emission limit values for new installations and vehicles would guarantee a level playing field for industries, but might not be sufficient to stimulate countries with high pollution levels to take measures to clean up the existing capital stock or to formulate additional effect based abatement measures.

Further work

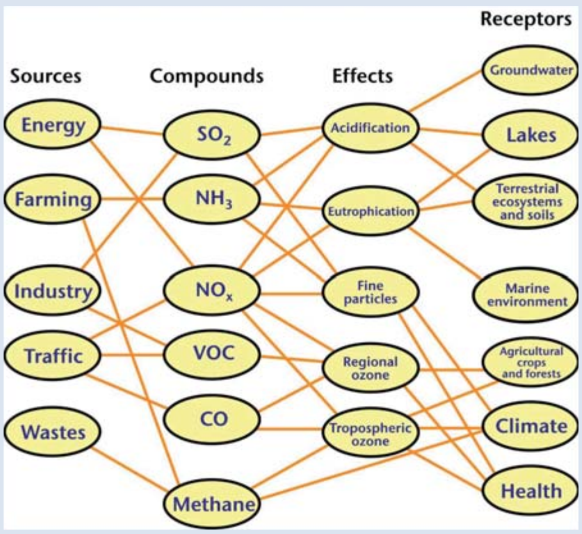
Improvement of emission data and further harmonisation of monitoring air quality and health and ecosystem impacts can help to assess policy progress. Exploring potential synergies between air pollution policies at the local, regional and hemispheric scale, as well as with energy and agricultural policies could identify cost-effective additional measures.

Capacity building in EECCA countries focused on improving emission inventories and assessment of abatement potentials would be necessary to stimulate the ratification process. Nevertheless, it is unclear whether this is sufficient. Although the potential additional emission reduction percentages in EECCA countries are significantly larger than in Western Europe, and the costs per additional life year saved are approximately half the costs of an additional costs per additional life year gained in Western Europe, the additional abatement costs when implement all technically feasible measures as a percentage of GDP are around four times higher than in Western Europe.

Common understanding of complexity

An important factor for success for air pollution abatement was the development of a common knowledge base including a scientific infrastructure aimed at joint monitoring and modelling programs. Moreover the frequent exchange of information with policy makers created mutual trust and learning. In contrast to the first technology and cost based protocols, in the 1990s an effect oriented approach was used in the second Sulphur Protocol, aiming at the most cost-effective way to reach acidification targets.

In the 1990s it was recognised that various air pollutants interact in the atmosphere, that they lead to combined impacts and that they often are caused by the same sources. This made a substance-by-substance approach less efficient and was the reason to develop a so-called multi-pollutant-multi-effect approach, including SO_2, NO_x, NH_3, VOC. The 1999 Gothenburg Protocol was the first protocol aimed at a cost-effective abatement of acidification, eutrophication and ground-level ozone impacts on human health and the environment. Later on the health impacts of fine particles were included in the analyses as well as the interactions with climate change.



(Revised from Grennfelt et al. 1994)

Over the past 40 years the LRTAP Convention has developed an extensive international network of scientists of various disciplines. Typical for the Convention is the frequent interaction between policy makers and scientists, which enabled a long term learning process, mutual trust and a common language. Joint measurement and modelling efforts created a common understanding of air pollution problems. The integrated assessment model GAINS played a central role in the communication between scientists and policy makers. It reflects the future expectations and the costs and impacts of policy options and enables to find the most cost-effective way to meet policy ambitions. The Task Force on Techno-Economic Issues assists the parties in exchanging knowledge on potential abatement measures.

With the Task Force on Hemispheric Transport of Air Pollution the scientific network is being extended across the Northern Hemisphere in order to compare models to assess the long range impacts of emission scenarios across the different continents: Europe, Asia and North America. This is a first step towards a co-ordinated approach to tackle hemispheric issues such as ozone and mercury.

Complexity is also enhanced due to the inevitable links between air pollution and climate change which increased the need for closer co-operation with climate experts of the UN-FCCC. Further co-operation on the issue of black carbon and other short lived climate pollutants is foreseen with UNEP, the Arctic Council and the Coalition on Clean Air and Climate.

Annex 1: Emission trends per country 1990-2010

Emission data as reported by the parties in 2015 and completed where needed with expert estimates from the EMEP-centres CEIP, CIAM and MSC-w and emission data from MACC-III (Monitoring Atmospheric Composition and Climate, Report on the update of global and European anthropogenic emissions, Technical Report COPERNICUS, Grant agreement 633080, 2015)

Total SO_x (as SO_2) emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Country emissions						
Albania	69,6	12,6	10,0	18,9	15,8	-77%
Armenia	38,1	4,3	1,0	1,5	1,7	-96%
Austria	74,5	47,5	31,7	26,7	18,7	-75%
Azerbaijan	181,3	214,6	214,3	111,5	31,3	-83%
Belarus	761,9	314,5	169,6	84,5	80,8	-89%
Belgium	365,5	258,4	173,7	143,0	60,6	-83%
Bosnia and Herzegovina	509,5	50,8	191,9	224,9	223,6	-56%
Bulgaria	1.099,0	1.295,2	861,3	776,4	386,8	-65%
Croatia	170,1	77,3	58,8	58,0	34,8	-80%
Cyprus	32,6	40,7	49,9	38,0	22,0	-33%
Czech Republic	1.309,0	922,8	300,5	210,9	174,4	-87%
Denmark	178,8	146,5	32,4	25,8	15,3	-91%
Estonia	273,6	116,1	97,0	76,3	83,2	-70%
Finland	262,5	99,1	79,3	69,2	66,8	-75%
France	1.288,2	965,9	628,0	461,1	285,3	-78%
Georgia	276,1	72,6	11,6	4,9	6,4	-98%
Germany	5.307,3	1.704,1	644,9	471,8	434,4	-92%
Greece	430,9	469,3	590,5	529,2	266,3	-38%
Hungary	825,3	620,3	427,5	41,2	31,2	-96%
Iceland	21,2	19,2	34,6	38,3	73,4	246%
Ireland	183,7	162,7	142,0	74,0	28,3	-85%
Italy	1.800,0	1.326,8	753,6	406,6	214,9	-88%
Kazakhstan	2.499,4	1.846,0	1.498,8	1.827,4	2.465,7	-1%
Kyrgyzstan	144,7	18,2	24,8	24,9	37,6	-74%
Latvia	99,5	47,8	15,1	6,3	2,6	-97%
Liechtenstein	0,1	0,0	0,0	0,0	0,0	-56%
Lithuania	169,0	69,2	37,1	31,4	20,7	-88%
Luxembourg	15,2	8,7	3,3	2,4	1,8	-88%
Malta	20,7	33,7	23,2	11,4	4,6	-78%
Montenegro	14,0	3,8	13,5	12,5	27,8	99%
Netherlands	191,8	129,4	73,1	64,6	34,1	-82%
Norway	52,3	33,8	27,2	24,0	19,7	-62%
Poland	3.210,0	2.255,2	1.451,5	1.217,4	937,3	-71%
Portugal	314,9	320,8	249,9	176,5	53,0	-83%
Republic of Moldova	187,5	42,0	8,5	7,4	4,4	-98%
Romania	1.336,5	1.161,0	817,8	641,9	364,3	-73%
Russian Federation - European Part	4.329,9	2.268,2	1.807,2	1.910,8	1.521,6	-65%
Russian Federation - Asian Part	1.838,3	1.141,9	1.237,2	1.666,0	1.982,7	8%
Serbia	489,7	509,9	474,0	436,4	422,2	-14%
Slovakia	526,0	246,0	127,0	89,0	69,4	-87%
Slovenia	198,7	122,2	92,7	40,8	9,9	-95%
Spain	2.091,3	1.798,5	1.463,9	1.254,8	400,7	-81%
Sweden	105,4	69,1	41,7	36,0	32,0	-70%
Switzerland	40,1	26,3	15,4	15,8	12,1	-70%

Total SO_x (as SO_2) emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Tajikistan	51,8	19,7	19,7	31,5	43,3	-16%
The former Yugoslav Republic of Macedonia	116,6	114,6	106,0	104,1	117,0	0%
Turkey	1.750,3	1.889,8	2.334,5	2.106,0	2.561,0	46%
Turkmenistan	128,7	81,4	101,2	129,8	212,5	65%
Ukraine	4.607,0	2.397,6	1.390,1	1.073,4	1.122,8	-76%
United Kingdom	3.681,5	2.365,6	1.217,3	709,6	427,6	-88%
Uzbekistan	517,5	419,7	507,1	659,8	991,1	92%
Total Country emissions	**44.187,0**	**28.381,2**	**20.682,7**	**18.204,9**	**16.455,3**	**-63%**
Area emissions in extended EMEP domain						
Arctic Ocean	0,0	0,0	0,0	0,0	0,0	7%
Baltic Sea	177,8	174,0	170,3	165,6	94,6	-47%
Black Sea	39,5	44,6	49,6	56,0	49,7	26%
Caspian Sea	26,4	16,4	17,8	23,9	28,5	8%
Mediterranean Sea	737,1	834,6	932,1	1.054,1	921,0	25%
North Sea	423,9	415,1	406,2	395,1	222,9	-47%
North-East Atlantic Ocean	458,1	518,4	580,7	656,6	612,6	34%
Aral Lake	8,0	4,9	5,6	9,1	12,3	54%
Other Asian Areas	673,3	819,3	980,3	1.269,0	1.553,9	131%
North Africa	199,3	235,6	303,5	361,0	487,1	144%
Total Area emissions	**2.743,4**	**3.062,9**	**3.446,1**	**3.990,4**	**3.982,6**	**45%**
Total (Countries and Areas)	**46.930,3**	**31.444,1**	**24.128,8**	**22.195,2**	**20.437,9**	**-56%**

Notes:

Data was downloaded from www.ceip.at 5th October 2015

Germany: Former German Democratic Republic and Former Federal Republic of Germany

Total NO_x (as NO_2) emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Country emissions						
Albania	15,0	9,8	15,4	19,4	17,9	19%
Armenia	60,9	8,0	12,3	14,3	19,4	-68%
Austria	215,5	194,1	210,2	235,0	179,6	-17%
Azerbaijan	149,3	94,1	82,0	99,9	100,7	-33%
Belarus	369,2	214,2	193,8	176,9	163,6	-56%
Belgium	413,0	384,2	346,6	319,8	252,3	-39%
Bosnia and Herzegovina	64,8	12,6	34,8	33,3	32,4	-50%
Bulgaria	264,1	165,4	144,5	179,1	138,5	-48%
Croatia	105,3	73,7	83,6	81,9	64,4	-39%
Cyprus	17,1	19,6	22,3	21,4	18,5	8%
Czech Republic	441,7	392,7	283,5	267,8	207,6	-53%
Denmark	299,3	289,6	224,3	201,6	145,3	-51%
Estonia	73,6	38,8	37,5	36,4	36,4	-51%
Finland	285,4	254,3	201,4	169,4	166,5	-42%
France	1.911,2	1.745,3	1.610,0	1.430,1	1.096,4	-43%
Georgia	120,6	28,7	22,6	25,0	31,0	-74%
Germany	2.882,3	2.167,1	1.925,4	1.573,2	1.333,7	-54%
Greece	437,2	470,3	450,3	401,5	290,0	-34%
Hungary	283,4	213,5	206,4	169,3	154,0	-46%
Iceland	27,8	29,9	27,8	26,1	22,9	-18%
Ireland	133,9	130,0	137,4	135,9	85,0	-37%
Italy	2.047,3	1.920,0	1.455,8	1.244,3	968,8	-53%
Kazakhstan	837,3	562,1	368,7	473,5	620,0	-26%
Kyrgyzstan	120,2	22,9	21,2	26,4	42,5	-65%
Latvia	94,2	52,3	44,1	44,4	38,4	-59%
Liechtenstein	0,8	0,7	0,7	0,7	0,6	-18%
Lithuania	128,4	61,8	50,7	54,3	49,6	-61%
Luxembourg	41,5	36,6	41,5	58,8	39,5	-5%
Malta	7,0	8,6	8,7	9,6	9,0	29%
Montenegro	7,6	3,0	8,9	7,5	9,8	28%
Netherlands	573,7	474,7	395,4	340,9	274,2	-52%
Norway	190,8	195,2	202,0	196,1	177,2	-7%
Poland	1.010,0	1.063,1	844,1	850,9	860,6	-15%
Portugal	233,5	264,5	261,8	254,7	177,1	-24%
Republic of Moldova	84,8	45,7	22,8	27,5	19,1	-77%
Romania	453,1	343,9	290,8	309,0	230,1	-49%
Russian Federation - European Part	4.641,4	3.015,0	2.777,3	2.979,5	2.390,9	-48%
Russian Federation - Asian Part	799,6	496,7	538,1	724,6	862,4	8%
Serbia	146,8	142,4	143,7	168,9	171,9	17%
Slovakia	222,0	178,0	107,4	101,9	88,6	-60%
Slovenia	62,7	60,3	52,5	49,5	47,1	-25%
Spain	1.269,7	1.315,8	1.299,6	1.322,5	890,9	-30%
Sweden	269,2	245,5	207,2	175,6	149,6	-44%
Switzerland	144,0	119,0	107,8	93,2	77,6	-46%

Total NO_x (as NO_2) emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Tajikistan	81,4	31,0	31,0	49,5	68,1	-16%
The former Yugoslav Republic of Macedonia	38,3	35,0	32,4	35,4	37,3	-3%
Turkey	564,0	703,0	840,0	879,0	945,0	68%
Turkmenistan	52,4	33,1	41,2	52,8	86,5	65%
Ukraine	2.134,6	1.201,8	888,3	875,0	690,1	-68%
United Kingdom	2.880,4	2.316,1	1.797,7	1.586,5	1.123,0	-61%
Uzbekistan	151,6	123,0	148,5	193,3	290,3	92%
Total Country emissions	**27.859,0**	**22.006,7**	**19.302,3**	**18.802,9**	**15.992,0**	**-43%**
Area emissions in extended EMEP domain						
Arctic Ocean	0,1	0,1	0,1	0,1	0,1	8%
Baltic Sea	232,3	258,7	285,2	318,2	267,2	15%
Black Sea	67,9	75,7	83,5	93,3	78,2	15%
Caspian Sea	11,1	6,9	7,5	10,1	12,0	8%
Mediterranean Sea	1.280,0	1.430,0	1.580,0	1.767,5	1.478,2	15%
North Sea	553,0	615,2	677,4	755,2	635,2	15%
North-East Atlantic Ocean	763,8	855,5	950,2	1.065,6	960,3	26%
Aral Lake	2,2	1,4	1,6	2,6	3,5	54%
Other Asian Areas	196,6	241,7	287,3	370,0	447,8	128%
North Africa	46,3	54,8	70,5	83,9	113,2	144%
Total Area emissions	**3.153,5**	**3.540,1**	**3.943,3**	**4.466,4**	**3.995,7**	**27%**
Total (Countries and Areas)	**31.012,5**	**25.546,7**	**23.245,5**	**23.269,3**	**19.987,7**	**-36%**

Notes:

Data was downloaded from www.ceip.at 5th October 2015

Germany: Former German Democratic Republic and Former Federal Republic of Germany

1

Total NH_3 emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Country emissions						
Albania	23,8	19,9	17,9	17,3	19,5	-18%
Armenia	10,9	9,8	9,7	11,1	13,4	23%
Austria	66,5	69,9	66,8	66,1	67,6	2%
Azerbaijan	35,8	33,4	38,5	47,0	52,7	47%
Belarus	194,3	130,1	114,5	117,4	153,2	-21%
Belgium	117,3	113,4	82,7	68,6	65,1	-44%
Bosnia and Herzegovina	23,2	11,2	16,8	18,4	18,7	-19%
Bulgaria	112,8	57,5	41,4	47,4	41,4	-63%
Croatia	56,2	40,9	41,1	42,1	38,8	-31%
Cyprus	5,3	6,1	6,0	6,0	5,6	5%
Czech Republic	133,1	98,4	92,1	75,9	66,9	-50%
Denmark	125,3	109,7	97,7	88,8	80,0	-36%
Estonia	25,6	11,8	9,7	10,1	10,6	-58%
Finland	37,8	36,0	37,5	39,2	38,2	1%
France	739,4	716,6	747,7	714,2	728,5	-1%
Georgia	35,6	32,3	38,2	42,1	47,2	32%
Germany	792,3	678,4	695,9	667,9	642,6	-19%
Greece	67,1	57,0	57,2	57,9	55,8	-17%
Hungary	156,6	90,9	94,0	88,6	77,4	-51%
Iceland	2,9	2,7	2,8	2,7	2,9	0%
Ireland	108,2	112,4	114,8	112,5	108,9	1%
Italy	471,3	451,7	453,2	421,1	387,8	-18%
Kazakhstan	193,7	184,7	97,9	123,4	132,6	-32%
Kyrgyzstan	33,3	26,2	25,6	27,8	31,5	-5%
Latvia	40,9	17,7	13,9	14,9	14,4	-65%
Liechtenstein	0,2	0,2	0,2	0,2	0,2	-8%
Lithuania	97,7	47,5	39,3	44,7	43,2	-56%
Luxembourg	4,9	5,0	5,2	4,8	4,7	-3%
Malta	1,7	1,6	1,7	1,7	1,5	-7%
Montenegro	6,4	5,9	5,5	3,7	2,8	-57%
Netherlands	372,5	230,3	181,7	160,0	143,7	-61%
Norway	24,3	24,9	26,1	27,5	27,4	13%
Poland	333,1	316,5	283,6	271,7	271,5	-19%
Portugal	69,4	63,9	64,7	49,2	46,2	-33%
Republic of Moldova	45,1	27,7	17,1	16,5	14,6	-68%
Romania	295,3	189,5	182,7	185,8	163,4	-45%
Russian Federation - European Part	1.191,4	785,7	551,4	492,8	530,2	-55%
Russian Federation - Asian Part	331,4	205,9	223,1	300,4	357,5	8%
Serbia	98,4	92,4	82,1	93,8	84,7	-14%
Slovakia	65,0	40,4	32,1	28,6	24,9	-62%
Slovenia	22,6	20,8	21,2	19,6	19,0	-16%
Spain	332,8	315,2	397,3	376,3	388,2	17%
Sweden	54,9	64,2	58,9	55,4	51,6	-6%
Switzerland	73,6	70,3	66,3	64,1	63,5	-14%

Total NH_3 emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Tajikistan	49,1	18,7	18,7	29,8	41,0	-16%
The former Yugoslav Republic of Macedonia	13,3	12,9	10,4	8,5	7,8	-41%
Turkey	509,9	472,5	482,1	495,9	484,6	-5%
Turkmenistan	35,5	22,4	27,9	35,7	58,5	65%
Ukraine	704,4	476,7	301,8	253,1	251,4	-64%
United Kingdom	344,0	330,6	322,3	304,4	279,0	-19%
Uzbekistan	54,5	44,2	53,4	69,5	104,3	92%
Total Country emissions	**8.740,9**	**7.004,8**	**6.470,7**	**6.322,1**	**6.367,0**	**-27%**
Area emissions in extended EMEP domain						
Other Asian areas	418,3	515,0	611,0	786,1	948,5	127%
North Africa	113,4	134,0	172,7	205,4	277,1	144%
Total (Countries and Areas)	**9.272,6**	**7.653,8**	**7.254,3**	**7.313,6**	**7.592,7**	**-18%**

Notes:

Data was downloaded from www.ceip.at 5th October 2015

Germany: Former German Democratic Republic and Former Federal Republic of Germany

Total NMVOC emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Country emissions						
Albania	39,5	37,6	28,6	34,1	32,3	-18%
Armenia	77,6	10,2	20,4	24,1	33,1	-57%
Austria	281,0	204,5	163,8	159,2	130,8	-53%
Azerbaijan	205,5	133,9	111,7	167,2	312,3	52%
Belarus	398,0	245,5	227,6	201,7	197,2	-50%
Belgium	341,4	290,6	227,5	185,8	155,4	-54%
Bosnia and Herzegovina	70,0	37,6	51,7	44,8	38,6	-45%
Bulgaria	598,5	144,8	98,9	99,4	103,3	-83%
Croatia	129,0	73,1	76,4	69,4	54,9	-57%
Cyprus	17,2	15,0	13,0	12,2	10,0	-42%
Czech Republic	335,4	261,7	261,0	172,3	143,8	-57%
Denmark	203,8	204,0	174,1	149,3	125,4	-38%
Estonia	70,6	50,0	45,0	40,0	35,4	-50%
Finland	256,6	218,2	166,0	136,4	116,2	-55%
France	2.469,1	2.062,4	1.681,0	1.239,0	874,3	-65%
Georgia	104,8	62,3	64,9	58,9	62,6	-40%
Germany	3.392,4	2.027,7	1.599,5	1.340,2	1.238,8	-63%
Greece	413,2	387,7	311,9	263,2	198,9	-52%
Hungary	268,5	195,4	176,1	146,3	125,1	-53%
Iceland	11,9	11,8	8,3	6,7	4,9	-59%
Ireland	135,3	128,2	112,3	105,9	91,4	-32%
Italy	1.936,0	1.974,4	1.523,5	1.242,1	942,2	-51%
Kazakhstan	512,2	375,5	372,8	480,7	638,6	25%
Kyrgyzstan	86,9	26,9	19,8	28,0	47,0	-46%
Latvia	141,3	115,3	102,1	99,7	89,2	-37%
Liechtenstein	1,0	0,7	0,5	0,4	0,4	-59%
Lithuania	120,7	95,5	71,9	76,3	71,5	-41%
Luxembourg	21,1	17,9	13,8	12,4	8,5	-60%
Malta	8,0	9,4	4,9	3,9	3,3	-58%
Montenegro	10,0	7,5	9,7	8,4	8,5	-16%
Netherlands	483,1	339,7	238,9	178,1	158,0	-67%
Norway	290,7	364,4	379,0	217,5	139,6	-52%
Poland	727,0	679,6	575,3	574,7	653,3	-10%
Portugal	266,1	262,6	248,2	209,0	179,9	-32%
Republic of Moldova	114,7	38,1	25,3	30,9	28,9	-75%
Romania	483,6	369,2	393,4	394,0	337,2	-30%
Russian Federation - European Part	3.772,1	2.847,7	2.691,9	2.684,1	2.245,7	-40%
Russian Federation - Asian Part	678,2	421,3	456,4	614,6	731,4	8%
Serbia	181,0	141,6	144,6	149,3	147,4	-19%
Slovakia	136,0	93,0	66,9	74,6	63,9	-53%
Slovenia	72,2	64,5	53,5	45,4	38,4	-47%
Spain	1.023,6	947,8	959,6	802,2	632,9	-38%
Sweden	360,2	278,1	224,1	201,7	191,6	-47%
Switzerland	302,4	199,6	143,5	102,3	90,2	-70%

Total NMVOC emissions (kt)	1990	1995	2000	2005	2010	difference 2010-1990 in %
Tajikistan	37,7	14,4	14,4	22,9	31,6	-16%
The former Yugoslav Republic of Macedonia	22,2	34,8	28,9	23,2	20,4	-8%
Turkey	835,7	909,5	954,5	919,2	977,3	17%
Turkmenistan	27,3	17,3	21,5	27,5	45,1	65%
Ukraine	1.246,5	651,6	574,5	595,0	481,3	-61%
United Kingdom	2.721,1	2.202,5	1.566,7	1.136,1	855,2	-69%
Uzbekistan	53,4	43,3	52,3	68,1	102,2	92%
Total Country emissions	**26.491,0**	**20.345,9**	**17.552,1**	**15.678,5**	**14.045,0**	**-47%**
Area emissions in extended EMEP domain						
Arctic Ocean	16,5	10,3	11,1	15,0	17,8	8%
Baltic Sea	7,5	8,1	8,6	9,3	6,9	-8%
Black Sea	2,0	2,3	2,5	2,8	2,4	15%
Caspian Sea	13,4	8,3	9,0	12,2	14,5	8%
Mediterranean Sea	38,2	42,6	47,0	52,6	44,0	15%
North Sea	17,9	19,2	20,5	22,1	16,6	-7%
North-East Atlantic Ocean	23,4	26,2	29,1	32,6	29,6	27%
Aral Lake	1,3	0,8	0,9	1,5	2,1	54%
Other Asian Areas	307,7	380,0	450,3	578,8	696,8	126%
North Africa	46,3	54,8	70,5	83,9	113,2	144%
Total Area emissions	**474,3**	**552,6**	**649,7**	**810,8**	**943,9**	**99%**
Total (Countries and Areas)	**26.965,4**	**20.898,5**	**18.201,9**	**16.489,3**	**14.988,9**	**-44%**

Notes:

Data was downloaded from www.ceip.at 5th October 2015

Germany: Former German Democratic Republic and Former Federal Republic of Germany

Total PM2.5 emissions (kt)	2000	2005	2010	difference 2010-2000 in %
Country emissions				
Albania	8,1	9,3	8,6	6%
Armenia	4,0	3,9	4,0	0%
Austria	23,5	22,6	19,6	-17%
Azerbaijan	15,3	16,9	18,4	21%
Belarus	57,7	54,5	51,0	-12%
Belgium	41,3	36,4	37,0	-11%
Bosnia and Herzegovina	16,2	20,4	14,7	-9%
Bulgaria	23,2	28,4	28,7	24%
Croatia	15,0	15,1	14,8	-1%
Cyprus	3,9	2,6	1,6	-59%
Czech Republic	41,1	27,6	27,4	-33%
Denmark	23,7	27,0	27,1	14%
Estonia	21,7	20,4	23,5	8%
Finland	40,5	38,5	40,4	0%
France	310,7	245,5	205,9	-34%
Georgia	28,1	19,1	19,7	-30%
Germany	158,2	133,4	124,6	-21%
Greece	66,0	60,5	45,2	-31%
Hungary	37,0	27,4	29,5	-20%
Iceland	0,6	0,8	1,8	199%
Ireland	20,7	19,4	16,8	-19%
Italy	163,1	140,1	126,0	-23%
Kazakhstan	107,4	113,8	173,0	61%
Kyrgyzstan	7,4	8,3	10,0	36%
Latvia	24,9	29,4	24,3	-2%
Liechtenstein	0,0	0,0	0,0	-3%
Lithuania	19,1	21,8	20,9	9%
Luxembourg	2,6	2,9	2,4	-11%
Malta	1,0	1,3	0,7	-25%
Montenegro	4,3	4,6	4,1	-6%
Netherlands	25,5	19,9	15,2	-40%
Norway	42,0	38,7	37,6	-10%
Poland	156,8	166,7	159,7	2%
Portugal	60,8	56,2	46,1	-24%
Republic of Moldova	10,8	10,5	9,7	-10%
Romania	159,2	114,7	128,8	-19%
Russian Federation - European Part	722,5	757,5	769,6	7%
Russian Federation - Asian Part	254,9	343,2	408,5	60%
Serbia	38,7	39,6	43,1	11%
Slovakia	22,7	36,7	26,6	17%
Slovenia	12,2	12,8	11,8	-4%
Spain	94,7	90,5	74,5	-21%
Sweden	25,2	26,3	25,0	-1%
Switzerland	10,6	9,5	8,5	-20%

Total PM2.5 emissions (kt)	2000	2005	2010	difference 2010-1990 in %
Tajikistan	11,6	18,6	25,6	119%
The former Yugoslav Republic of Macedonia	13,9	12,2	11,7	-16%
Turkey	471,2	442,8	541,1	15%
Turkmenistan	28,2	36,2	59,3	110%
Ukraine	388,3	391,6	357,1	-8%
United Kingdom	120,5	96,0	86,9	-28%
Uzbekistan	101,2	131,7	197,8	95%
Total Country emissions	**4.058,2**	**4.003,9**	**4.165,9**	**3%**
Area emissions in extended EMEP domain				
Arctic Ocean	0,0	0,1	0,1	60%
Baltic Sea	18,9	18,9	13,7	-28%
Black Sea	5,5	6,2	5,5	0%
Caspian Sea	3,6	4,9	5,8	60%
Mediterranean Sea	103,7	117,2	102,5	-1%
North Sea	44,9	45,0	32,2	-28%
North-East Atlantic Ocean	65,2	73,7	64,2	-2%
Aral Lake	0,9	1,5	2,0	122%
Other Asian Areas	124,5	161,3	197,7	59%
North Africa	44,2	52,5	70,9	60%
Total Area emissions	**411,4**	**481,3**	**494,6**	**20%**
Total (Countries and Areas)	**4.469,6**	**4.485,2**	**4.660,5**	**4%**

Notes:

Data was downloaded from www.ceip.at 5th October 2015

Germany: Former German Democratic Republic and Former Federal Republic of Germany

List of authors and contributors

A1: *Marie-Eve Héroux, Markus Amann, Bill Harnett and colleagues, HC Hanson, Till Spanger, Eli-Marie Asen, Ivan Angelov*

A2: *David Fowler & Dick Wright, Heleen de Wit, Kjetil Törseth, Katja Mareckova, Anne-Christine LeGall, Isaura Rabago, Jean-Paul Hettelingh*

A3: *David Fowler & Dick Wright, Heleen de Wit, Kjetil Törseth, Katja Mareckova, Anne-Christine LeGall, Isaura Rabago, Jean-Paul Hettelingh, Johan Tidblad, Hilde Fagerli*

A4: *Frank Dentener, David Simpson, Oliver Wild, Zig Klimont, Augustin Colette, Oksana Tarasova, Sverre Solberg, Harry Harmens, Hilde Fagerli, Gina Mills*

A5: *Sergey Dutchak, John Munthe, Ramon Guardans,Gudrun Schütze, Alexander Romanov, Kut Breivik, Wenche Aas, Athanasios Katsoyiannis*

B1: *Rob Maas, Stefan Aström*

B2: *Markus Amann*

B3: *Frank Dentener, Zbigniew Klimont, Oliver Wild, Oleg Travnikov, Augustin Colette, Harry Harmens, Gina Mills, Hilde Fagerli.*

B4: *Rob Maas, Markus Amann*

B5: *Stefan Reis, John Munthe, Alexander Romanov, Ramon Guardans, Sergey Dutchak*

References

A1:

Aphekom Summary Report. 2011. Aphekom - Summary report of the Aphekom project 2008-2011. Available: http://www.aphekom.org/c/document_library/get_file?uuid=5532fafa-921f-4ab1-9ed9-c0148f7da36a&groupId=10347 .

EC. 2013. Commission staff working document: Impact assessment accompanying the documents. Brussels: European Commission. Available: http://ec.europa.eu/environment/archives/air/pdf/Impact_assessment_en.pdf.

EEA 2014. Air quality in Europe - 2014 report. EEA Report No 5/2014. Copenhagen, Denmark: European Environment Agency. Available: http://www.eea.europa.eu/publications/air-quality-in-europe-2014.

Holland, M. 2013. Cost–benefit Analysis of Final Policy Scenarios for the EU Clean Air Package. Version 2, Corresponding to IIASA TSAP Report #12,Version 2a. October 2014. Available: http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf .

Laden, Francine, Schwartz, Joel, Speizer, Frank E & Dockery, Douglas W 2006. Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. American journal of respiratory and critical care medicine, 173 (6), 667-672.

Lepeule, Johanna, Laden, Francine, Dockery, Douglas W & Schwartz, Joel David 2012. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environmental Health Perspectives, 120 (7), 965-970.

Lim, Stephen S., Vos, Theo, Flaxman, Abraham D., Danaei, Goodarz, Shibuya, Kenji, Adair-Rohani, Heather, AlMazroa, Mohammad A., Amann, Markus, Anderson, H. Ross, Andrews, Kathryn G., Aryee, Martin, Atkinson, Charles, Bacchus, Loraine J., Bahalim, Adil N., Balakrishnan, Kalpana, Balmes, John, Barker-Collo, Suzanne, Baxter, Amanda, Bell, Michelle L., Blore, Jed D., et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet, 380 (9859), 2224-2260. Available: http://www.sciencedirect.com/science/article/pii/S0140673612617668.

Loomis, Dana, Grosse, Yann, Lauby-Secretan, Béatrice, Ghissassi, Fatiha El, Bouvard, Véronique, Benbrahim-Tallaa, Lamia, Guha, Neela, Baan, Robert, Mattock, Heidi & Straif, Kurt 2013. The carcinogenicity of outdoor air pollution. The Lancet Oncology, 14 (13), 1262-1263.

UNECE. 2015. United Nations Economic Commission for Europe. The 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone [Online]. United Nations Economic Commission for Europe. Available: http://www.unece.org/env/lrtap/multi_h1.html .

UNEP 2014. Proceedings of the United Nationsl Environment Assembly of the United Nations Environment Programme at its first session. Available: http://www.unep.org/unea/docs/Compilation_of_decisions_and%20resolutions_advanced_unedited%20copy.pdf

WHO. 2014. Burden of disease from ambient and household air pollution [Online]. Geneva, Switzerland: World Health Organization. Available: http://www.who.int/phe/health_topics/outdoorair/databases/en/ .

WHO 2015. Health and the Environment: Addressing the health impact of air pollution. Draft resolution proposed by the delegations of Albania, Chile, Colombia, France, Germany, Monaco, Norway, Panama, Sweden, Switzerland, Ukraine, United States of America, Uruguay and Zambia. Agenda item 14.6, A68/A/CONF./2 Rev.1. Sixty-Eighth World Health Assembly World Health Organization. Available: http://apps.who.int/gb/ebwha/pdf_files/WHA68/A68_ACONF2Rev1-en.pdf?ua=1.

WHO Regional Office for Europe. 2006. Air quality guidelines for particular matter, ozone, nitrogen dioxide and sulphur dioxide - Global update 2005. Copenhagen, Denmark: WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf .

WHO Regional Office for Europe. Parma declaration on Environment and Health. Fifth Ministerial Conference on Environment and Health, 2010 Parma. World Health Organization. Available: http://www.euro.who.int/__data/assets/pdf_file/0011/78608/E93618.pdf?ua=1

WHO Regional Office for Europe. 2013a. Review of evidence on health aspects of air pollution–(REVIHAAP). Technical Report. World Health Organization Regional Office for Europe Available: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report

WHO Regional Office for Europe 2013b. Health Effects of Particulate Matter: Policy Implications for Countries in Eastern Europe, Caucasus and Central Asia. Copenhagen, Denmark, World Health Organization Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf?ua=1
WHO Regional Office for Europe. 2014. Almost 600 000 deaths due to air pollution in Europe: new WHO global report. [Online]. Copenhagen, Denmark: WHO Regional Office for Europe Available: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/news/news/2014/03/almost-600-000-deaths-due-to-air-pollution-in-europe-new-who-global-report
WHO Regional Office for Europe 2015a. Environment and Health Information System (ENHIS) [online database]. Copenhagen, Denmark: WHO Regional Office for Europe. Available: http://www.euro.who.int/en/data-and-evidence/environment-and-health-information-system-enhis.
WHO Regional Office for Europe 2015b. Environment and Health Information System (ENHIS) [online database], 3.3 Exposure to particulate matter in outdoor air. Copenhagen, Denmark: WHO Regional Office for Europe. Available: http://data.euro.who.int/eceh-enhis/Default2.aspx?indicator_id=10
WHO Regional Office for Europe, OECD. 2015c. Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. Copenhagen, Denmark: World Health Organization Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf?ua=1

A2 & A3:

Fowler et al 2015, Effects of global change during the 21st century on the nitrogen cycle. Atmos. Chem. Phys. Discuss. 15, 1747-1868.
Garmo ØA, Skjelkvåle BL, De Wit HA, Colombo L, Curtis C, Fölster J, Hoffmann A, Hruška J, Høgåsen T, Jeffries DS, Keller WB, Krám P, Majer V, Monteith DT, Paterson AM, Rogora M, Rzychon D, Steingruber S, Stoddard JL, Vuorenmaa J, Worsztynowicz A, 2014. Trends in surface water chemistry in acidified areas in Europe and North America from 1990 to 2008. Water, Air and Soil Pollution 225: 1880; DOI: 10.1007/s11270-014-1880-6
Hesthagen, T, Fjellheim, A, Schartau, A K, Wright, R F, Saksgård, R and Rosseland, B O (2011) Chemical and biological recovery of Lake Saudlandsvatn, a formerly highly acidified lake in southernmost Norway, in response to decreased acid deposition Science of the Total Environment 409 (2011) 2908–2916
Hettelingh, J-P., M. Posch, J. Slootweg, G.J. Reinds, W. de Vries, A.-C. Le Gall and R. Maas, 2015. Effects-based integrated assessment modelling for the support of European air pollution abatement policies. In W. de Vries, J-P. Hettelingh & M. Posch (eds) Critical Loads and Dynamic Risk Assessments: Nitrogen, Acidity and Metals in Terrestrial and Aquatic Ecosystems. Springer, Dordrecht, Netherlands: 613-635.
Nilsson, J. and Grennfelt P. (1988) Critical Loads for Sulphur and Nitrogen. Nordic Council of Ministers. Report NORD 1988:15.
Posch M., Slootweg J., Hettelingh J-P. (eds) (2012) Modelling and Mapping of Atmospherically-induced Ecosystem Impacts in Europe, CCE Status Report 2012, Coordination Centre for Effects, RIVM, Bilthoven, The Netherlands.
Rafaj, P, Amann, M, Siri, J and Wuester, H (2014) Changes in European greenhouse gas and air pollutant emissions 1960–2010: decomposition of determining factors. Clim.Change 24(3)477-504.
Reis S, Grennfelt P, Klimont Z, Amann M, ApSimon H, Hettelingh J-P, Holland M, LeGall A-C, Maas R, Posch M, Spranger T, Sutton MA, Williams M, 2012. From acid rain to climate change. Science 338, 1153–1154
Stevens CJ, Duprè C, Dorland E, Gaudnik C, Gowing DJG, Bleeker A, Diekmann M, Alard D, Bobbink R, Fowler D, Corcket E, Mountford JO, Vandvik V, Aarrestad PA, Muller S, Dise NB, 2010. Nitrogen deposition threatens species richness of grasslands across Europe. *Environmental Pollution* 158: 2940–2945
Sutton M.A., Howard C., Erisman J.W., Billen G., Bleeker A., Grennfelt P., van Grinsven H. and Grizzetti B. (Eds.) (2011) The European Nitrogen Assessment Cambridge University Press.
Tammi, J., Appelberg, M, Beier, U, Hesthagen, T, Lappalainen, A and Rask, M (2003) Fish Status Survey of Nordic Lakes: Effects of Acidification, Eutrophication and StockingActivity on Present Fish Species Composition. Ambio, Vol. 32, No. 2, 98-105.
(Tidblad J, Kucera V, Ferm M, Kreislova K, Brüggerhoff S, Doytchinov S, Screpanti A, Grøntoft T, Yates T, De la Fuente, D Roots O, Lombardo T, Simon S, Faller M, Kwiatkowski L, Kobus J, Varotsos C, Tzanis C, Krage L, Schreiner M, Melcher M, Grancharov I, Karmanova N, 2012. Effects of air pollution on materials and cultural heritage: ICP Materials celebrates 25 years of research. International Journal of Corrosion, Volume 2012, Article ID 496321 (16 pp); DOI: 10.1155/2012/496321)

Tidblad J, Grøntoft T, Kreislova K, Faller M, De la Fuente D, Yates T, Verney-Carron A, 2014.Trends in pollution, corrosion and soiling 1987-2012. UNECE ICP Materials Report No 76, Swerea KIMAB

Van Grinsven, H. J. M., Holland, M., Jacobsen, B. H., Klimont, Z., Sutton, M. and Willems, W. J. (2013) Costs and Benefits of Nitrogen for Europe and Implications for Mitigation. *Environ. Sci. Technol., 2013, 47 (8), pp 3571–3579*

A4:

Ainsworth EA, Yendrek CR, Sitch S, Collins WJ, Emberson LD (2012) The effects of tropospheric ozone on net primary production and implications for climate change. Annual Review of Plant Biology 63: 637-661.

Colette, A., C. Granier, Ø. Hodnebrog, H. Jakobs, A. Maurizi, A. Nyiri, B. Bessagnet, A. D'Angiola, M. D'Isidoro, M. Gauss, F. Meleux, M. Memmesheimer, A. Mieville, L. Rouïl, F. Russo, S. Solberg, F. Stordal, and F. Tampieri, Air quality trends in Europe over the past decade: a first multi-model assessment Atmos. Chem. Phys., 11, 11657-11678, 2011

Cooper, O.R., D.D. Parrish, J. Ziemke, N.V. Balashov, M. Cupeiro, I.E. Galbally, S. Gilge, L. Horowitz, N.R. Jensen, J.-F. Lamarque, V. Naik, S.J. Oltmans, J. Schwab, D.T. Shindell, A.M. Thompson, V. Thouret, Y. Wang, and R.M. Zbinden, 2014: Global distribution and trends of tropospheric ozone: An observation-based review. Elementa Sci. Anthropocene, 2, 000029, doi:10.12952/journal.elementa.000029.

Doherty, R.M., Atmospheric chemistry: Ozone pollution from near and far, Nature Geosci, 9, 664-665, 2015.

EEA, Air quality in Europe — 2014 report, European Environment Agency Report, Copenhagen, Denmark, ISBN 978-92-9213-490-7, No 5/2014.

EMEP, MSC-W & CCC & CEIP Status Report on "Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components, EMEP Report 1/2015, ISSN 1504-6109, 2015.

Mills, G., Harmens, H. (eds). (2011). Ozone pollution: A hidden threat to food security. Programme Coordination Centre for the ICP Vegetation, Centre for Ecology & Hydrology, Bangor, UK. ISBN 978-1-906698-27-0

Mills, G., Hayes, F., Simpson, D., Emberson, L., Norris, D., Harmens, H., and Büker, P. 2011. Evidence of widespread effects of ozone on crops and (semi-)natural vegetation in Europe (1990 – 2006) in relation to AOT40 – and flux-based risk maps. Global Change Biology, 17, 592-613.

REVIHAAP, Review of evidence on health aspects of air pollution – REVIHAAP Project Technical Report, World Health Organisation, 2013.

Simpson, D., Arneth, A., Mills, G., Solberg, S. & Uddling, J. Ozone - the persistent menace; interactions with the N cycle and climate change. Current Op. Environ. Sust., 2014, 9-10, 9-19, http://dx.doi.org/10.1016/j.cosust.2014.07.008

TFMM: Task Force Models and Measurements Trend report, in preparation, 2015.

Van Dingenen, R., F.J. Dentener, F. Raes, M.C. Krol, L. Emberson, J.Cofala, The global impact of ozone on agricultural crop yields under current and future air quality legislation, Atmos. Env, 43 (3), p. 605-618, 2009.

WGE trend report, 2015, in preparation.

Verstraeten, W.W., Neu, J. L.,Williams, J.E., Bowman, K.W., Worden, J.R., Boersma, K. F., Rapid increases in tropospheric ozone production and export from China, Nature Geosci, 8, 690-695, 2015.

Wild, O., A.M. Fiore, D.T. Shindell, R.M. Doherty, W.J. Collins**,** F.J. Dentener, M.G. Schultz, S. Gong, I. A. MacKenzie, G. Zeng, P. Hess, B.N. Duncan, D.J. Bergmann, S. Szopa, J.E. Jonson, T.J. Keating, and A. Zuber, Future Changes in Surface Ozone: A Parameterized Approach, Atmos. Chem. Physics, 12, 2037–2054, 2012.

A5:

Aas W, Nizzetto PB, 2014. Heavy metals and POP measurements, 2012. EMEP/CCC Report 4/2014. http://www.nilu.no/projects/ccc/reports/cccr4-2014.pdf

EEA and CEIP, 2014. Inventory Review 2014. Review of emission data reported under the LRTAP Convention and NEC Directive. http://www.ceip.at/fileadmin/inhalte/emep/pdf/2014/DP-143_InventoryReport_2014_forWeb.pdf

Tørseth K, Aas W, Breivik K, Fjæraa AM, Fiebig M, Hjellbrekke AG, Lund Myhre C, Solberg S, Yttri KE, 2012. Introduction to the European Monitoring and Evaluation Programme (EMEP) and observed atmospheric composition change during 1972-2009. Atmospheric Chemistry and Physics. Vol. 12: 5447-5481. doi:10.5194/acp-12-5447-2012

WEOG, 2015. Global monitoring plan for persistent organic pollutants under the Stockholm Convention Article 16 on effectiveness evaluation. 2nd regional monitoring report, Western Europe and others group (WEOG) region. In press will be available in a few weeks at: http://chm.pops.int/Implementation/GlobalMonitoringPlan/MonitoringReports/tabid/525/Default.aspx

Ilyin I., O.Rozovskaya, O.Travnikov, M.Varygina and W.Aas [2014]. **Heavy Metals: Transboundary Pollution of the Environment.** EMEP Status Report 2/2014.

Gusev A., Rozovskaya O., Shatalov V., Aas W. and Nizzetto P.. [2014]. **Persistent Organic Pollutants in the Environment.** EMEP Status Report 3/2014.

Travnikov O., Ilyin I., Rozovskaya O., Varygina M., Aas W., Uggerud H.T., Mareckova K. and Wankmueller R. [2012]. **Long-term Changes of Heavy Metal Transboundary Pollution of the Environment (1990-2010).** EMEP Status Report 2/2012.

Holy M., Pesch R., Schröder W., Harmens H., Ilyin I., Alber R., Aleksiayenak Y., Blum O., Coşkun M., Dam M., De Temmerman L., Fedorets N., Figueira R., Frolova M., Frontasyeva M., Goltsova N., González Miqueo, L., Grodzińska K., Jeran Z., Korzekwa S., Krmar M., Kubin E., Kvietkus K., Larsen M., Leblond S., Liiv S., Magnússon S., Maňkovská B., Mocanu R., Piispanen J., Rühling Å., Santamaria J., Steinnes E., Suchara,I., Thöni L., Turcsányi G., Urumov V., Wolterbeek H.T., Yurukova L., Zechmeister H.G. [2010]. First thorough identification of factors associated with Cd, Hg and Pb concentrations in mosses sampled in the European Surveys 1990, 1995, 2000 and 2005. *Journal of Atmospheric Chemistry* 63, 109-124.

B3:

Alexandratos, N., Bruinsma, J., 2012. World agriculture towards 2030/2050, the 2012 revision (No. No. 12-03), ESA Working Paper. World Food and Agricultural Organization, Rome, Italy.

Amann, M., Bertok, I., Borken, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Rafaj, P., Schoepp, W., Wagner, F., 2011. Cost-effective Emission Reductions to Improve Air Quality in Europe in 2020. Analysis of Policy Options for the EU for the Revision of the Gothenburg Protocol. NEC Scenario Analysis Report #8. International Institute for Applied Systems Analysis

Amann, M., Z. Klimont, and F. Wagner, 2013. Regional and Global Emissions of Air Pollutants: Recent Trends and Future Scenarios. Annu. Rev. Environ. Resour. 38/1, 31–55.

International Energy Agency, 2012. Energy Technology Perspectives. 2012 - Pathways to a Clean Energy System. OECD/IEA, Paris.

Klimont, Z., Hoeglund-Isaksson, L., Heyes, C., Rafaj, P., Schoepp, W., Cofala, J., Borken-Kleefeld, J., Purohit, P., Kupiainen, K., Winiwarter, W., Amann, M., Zhao, B., Wang, S., Bertok, I., Sander, R., in preparation. Global scenarios of air pollutants and methane: 1990-2050.

Shatalov, V., Ilyin I., Gusev, A., Travnikov O., 2015, Heavy Metals and Persistent Organic Pollutants: Multi-scale modelling and trend analysis methodology, MSC-E Technical Report, http://www.msceast.org/reports/1_2015.pdf

Van Vuuren, D.P., Edmonds, J.A., Kainuma, M., Riahi, K., Thomson, A.M., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S., 2011. The representative concentration pathways: an overview. Clim. Change 109, 5–31. doi:10.1007/s10584-011-0148-z

Wang, S. X., Zhao, B., Cai, S. Y., Klimont, Z., Nielsen, C., McElroy, M. B., Morikawa, T., Woo, J. H., Kim, Y., Fu, X., Xu, J. Y., Hao, J. M., and He, K. B.: Emission trends and mitigation options for air pollutants in East Asia, Atmos. Chem. Phys. Discuss., 14, 2601-2674

Wild, O., A.M. Fiore, D.T. Shindell, R.M. Doherty, W.J. Collins, F.J. Dentener, M.G. Schultz, S. Gong, I. A. MacKenzie, G. Zeng, P. Hess, B.N. Duncan, D.J. Bergmann, S. Szopa, J.E. Jonson, T.J. Keating, and A. Zuber, Future Changes in Surface Ozone: A Parameterized Approach, Atmos. Chem. Physics, 12, 2037–2054, 2012.

Zhao, B., S.X. Wang, H. Liu, J.Y. Xu, K. Fu, Z. Klimont, J.M. Hao, K.B. He, J. Cofala, and M. Amann, 2013. NOx emissions in China: historical trends and future perspectives. Atmos. Chem. & Phys., 13, 9869-9897

B4:

UNEP/WMO,

IIASA, ..

TFRN,

UN,

B7:

Raes, Swart, 2007, …

Reis S, Grennfelt P, Klimont Z, Amann M, ApSimon H, Hettelingh J-P, Holland M, LeGall A-C, Maas R, Posch M, Spranger T, Sutton MA, Williams M (2012) From Acid Rain to Climate Change. *Science* 338(6111), 1153-1154.

Voinov A, Seppelt R, Reis S, Nabel JEMS, Shokravi, S (2014) Values in socio-environmental modelling: Persuasion for action or excuse for inaction. *Environmental Modelling & Software* 53, 207–212, http://dx.doi.org/10.1016/j.envsoft.2013.12.005