UNECE

Towards Cleaner Air

Scientific Assessment Report 2016

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Preface

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 (CLRTAP). The EMEP Steering Body and the Working Group on Effects cover the scientific network within the UNECE region. This network was developed over the past 35 years in order to support effect-based cost-effective air pollution policies with the best available knowledge.

This assessment report summarises current scientific knowledge on transboundary air pollution issues within the UNECE region and describes the effectiveness of air pollution measures in addressing large-scale effects on forests and lakes as well as in protecting human health and preventing other air pollution effects, such as loss in biodiversity and damage to crops, the built environment and cultural heritage.

The assessment of emission reduction achievements is based on a report on trends in air pollution and impacts coordinated by the Working Group on Effects[i], a report on air pollution trends between 1990 and 2012 by the EMEP Task Force on Measurements and Modelling[ii], and an assessment for North America by the U.S. Environmental Protection Agency (EPA) and Environment and Climate Change Canada[iii].

Opportunities identified for means to tackle remaining challenges are mainly based on 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 aim of this assessment is to serve as a basis for considering new directions for policy development and for identifying policy-relevant research questions. The international co-operative approach, which includes interaction between science and policy, as developed under the Convention, provides a good basis for exploring synergies between air pollution and climate change, agriculture and biodiversity, and energy and public health policies on the urban, national, continental and hemispheric scale.

We are indebted to the editorial board of the Assessment Report: Markus Amann, Hilde Fagerli, David Fowler, Laurence Rouil and Martin Williams, as well as to the Secretariat of the Arctic Monitoring and Assessment Programme for the technical editing and production of this report. We thank the Nordic Council of Ministers and the governments of Germany, Netherlands, Norway, Sweden and Switzerland for their financial support and CCE, CEH, CEIP, IIASA, INERIS, IVL, JRC-IES, MSC-E, MSC-W, RIVM and WHO for their contribution in kind.

Rob Maas, Peringe Grennfelt, editors

Contents

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Summary for **Policymakers**

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Key Findings

1 Abatement measures under the 1979 Convention on Long-range Transboundary Air Pollution (CLRTAP) and its protocols have achieved significant success. There has been a sharp decline in emissions, especially for sulphur, and economic growth and trends in air pollution have been progressively decoupled.

2 Despite successes – abatement has resulted in an extra year of average life expectancy in Europe, soil acidification has been halted in most parts of Europe, and declining acidification in lakes has led to fish stocks recovering in areas where they had largely disappeared – problems still exist.

3 A significant proportion of the urban population in Europe and North America is exposed to concentrations of fine particles and ozone that are near or above the WHO guideline level and, despite soils and lakes recovering from acidification across large parts of Europe, nitrogen deposition in many parts still exceeds the level below which harmful effects do not occur.

4 Because transboundary sources are often major contributors to urban pollution, many European cities will be unable to meet WHO guideline levels for air pollutants through local action alone. Even national and Europe-wide action may not be enough in some cases.

5 Long-term risks due to ozone, heavy metals and persistent organic pollutants continue to exist in many UNECE countries. In addition to implementing CLRTAP Protocols, reducing background levels and exposure will require broader coordination beyond the European or North American scale, as well as coordination with other international fora such as the Minamata Convention on Mercury and the Stockholm Convention on Persistent Organic Pollutants.

6 Technical measures are available to reduce fine particles and ozone to levels below the WHO guidelines in most parts of Europe and North America and to avoid excess nitrogen in most nature areas. Successful examples of healthy lifestyles that contribute to cleaner air are also available.

7 Air pollution control costs are generally significantly lower than the costs of damage to health and the environment. In many countries the net impact of abatement measures on national income and employment will be neutral because production of the technologies required will also create employment.

8 An integrated approach to climate change and air pollution could lead to significant co-benefits, as well as to reducing the risk of applying climate change measures with significant negative impacts on air quality.

9 Ratification and implementation of the 2012 revision of the Gothenburg Protocol would reduce emissions of sulphur dioxide, nitrogen oxides and particulate matter by 40–45% between 2005 and 2020, according to estimates made in 2011. For ammonia the reduction would be 17%. Ratification enables a regionally-level playing field for industries and so prevents countries from competing with each other at the expense of the environment and health. Exploring synergies between air pollution policy at the local, regional and hemispheric scale, as well as with energy, transport and agricultural policy, could help identify additional cost-effective measures.

10 International policy collaboration and coordination of air pollution science remains essential to harmonise methods for estimating emissions, monitoring air quality and impacts, and identifying cost-effective further steps.

Introduction

Viewed largely as a local issue during the 1950s and 1960s, air pollution began to be acknowledged as a larger-scale issue during the 1970s and 1980s. This is when it became clear that widespread acidification of forests and lakes in northern Europe could only have been caused by pollutants carried into the region by air masses moving across industrial regions in countries far away from the problems. These long-range impacts became the main drivers for the development of joint scientific and monitoring efforts as well as for policy negotiations under the Convention on Long-range Transboundary Air Pollution (CLRTAP).

Since its establishment in 1979, primarily to deal with problems of air pollution on a broad regional basis the Convention has promoted a mutual exchange of information between scientists and policymakers. Coupled with good intergovernmental cooperation this has resulted in a sharp reduction in emissions, particularly for sulphur dioxide. Soil acidification has been halted in most parts of Europe and declining acidification in lakes has resulted in the recovery of fish stocks in areas where they had all but disappeared.

Despite clear successes and good cooperation facilitated by the Convention among countries of the northern hemisphere, including those of North America, current scientific findings show air pollutants (including fine particles, ozone, nitrogen, heavy metals and persistent organic pollutants) are still causing health and ecosystem effects in the UNECE region.

Abatement measures see significant success

Abatement measures for sulphur under the Convention have prevented emissions in Europe from more than doubling over the past 30 years. In fact, by applying measures such as flue gas desulphurisation and low-sulphur fuels, countries have achieved a total reduction in sulphur emissions of about 80% since 1990. Abatement measures for nitrogen oxides, which include flue gas cleaning

ACIDIFICATION – A SUCCESS STORY

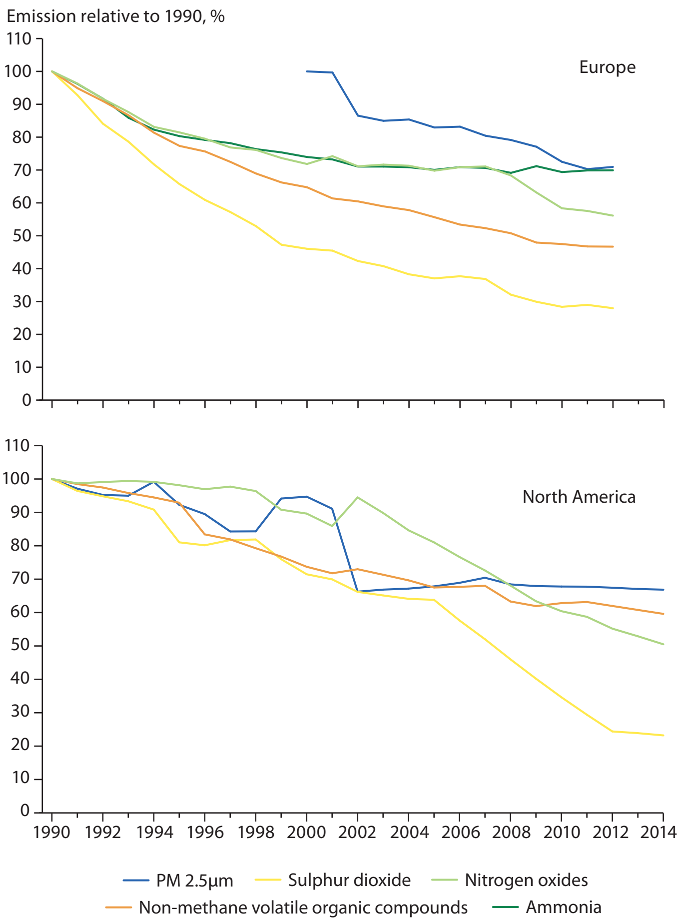
Addressing the health impacts of particulate matter presents comparable challenges to those of the acidification problem in the 1970s, in that the particles causing measurable effects primarily originate from long-distance sources. The successful international response to the highly visible acidification damage to lakes, forests and buildings was to address combustion sources and human and natural receptors simultaneously. This led to the understanding that most combustion sources emit compounds that affect both human and ecosystem health. For example, policy efforts to reduce acidification through sulphur abatement (and so improve ecosystem health) also resulted in lower particulate emissions (thus protecting human health). Another example concerns regulations to reduce nitrogen oxide and volatile organic compound emissions from vehicle exhaust; introducing the unleaded petrol needed for catalytic converters to work (originally aimed at improving ecosystem health) caused a decline in lead emissions (thus protecting human health). Acknowledging that action to reduce nitrogen emission from combustion sources had multiple benefits was the start of the multi-effect approach to tackling air pollution under the Convention.

and catalytic converters in cars have roughly halved emissions over this period. As the use of cleaner technologies in industry and transport within the UNECE region has increased so the costs of applying them have declined. Particulate matter concentrations at European EMEP sites declined by around a third between 2000 and 2012. The number of days on which ozone concentrations exceed the **WHO guideline level** is now about 20% lower than in 1990. Ambient levels of **$PM_{2.5}$** have also declined in North America. Between 2000 and 2012, national average annual concentrations fell by 33% in the United States and 4% in Canada. The decline in fine particle emissions is largely through harmonised controls on diesel vehicles and engines. In the United States and Canada, national average ozone levels are now 23% and 15% (2014) lower than in 1990.

Economic growth (growth in production and consumption) and trends in air pollution (changes in emissions) have been progressively decoupled. In western Europe, environmental measures were responsible for around a third of this decoupling. Energy policy and general technological progress were also important. Environmental measures and energy policy will continue to drive future improvements in air quality.

In the United States, implementing the Clean Air Act between 1970 and 2014 achieved a 69% reduction in emissions of carbon monoxide, lead, nitrogen oxides, volatile organic compounds, particulate matter and sulphur dioxide, despite a marked increase in GDP (238%), vehicle miles travelled (172%), energy consumption (45%) and population (56%). In Canada, the period 1990 to 2014 saw a marked reduction in emissions of $PM_{2.5}$ (57%; excluding open sources), sulphur dioxide (63%) and nitrogen oxides (33%) together with strong growth in GDP (75%) and population (28%).[iv]

If economic growth and air pollution trends had not been decoupled, exceedance of **critical loads** for acidification in Europe would have been 30 times higher than today, and three times higher for nitrogen. Average $PM_{2.5}$ levels would have been similar to levels in current European 'hot spots', with three times more health impacts than today and the premature death of 600,000 more people. Health impacts from ozone would have been 70% higher and ozone damage to crops 30% higher. Overall, average life expectancy is today 12 months more than in the hypothetical unabated world.[v]



▲ *For a range of pollutants, in the European ECE-region (upper) and North American ECE-region (lower), the decline in emissions over recent decades is steepest for sulphur.*[vi]

WHO GUIDELINE LEVELS In order to protect health, in 2005 the WHO formulated scientifically-based air quality guideline values that can be used by countries as long-term targets on a voluntary basis. Based on the latest science and including the WHO guidelines, the EU, the US, Canada and other countries have each put in place air quality standards that also take into consideration a number of other factors. The values for these air quality standards are reviewed and updated as appropriate, on a regular basis.

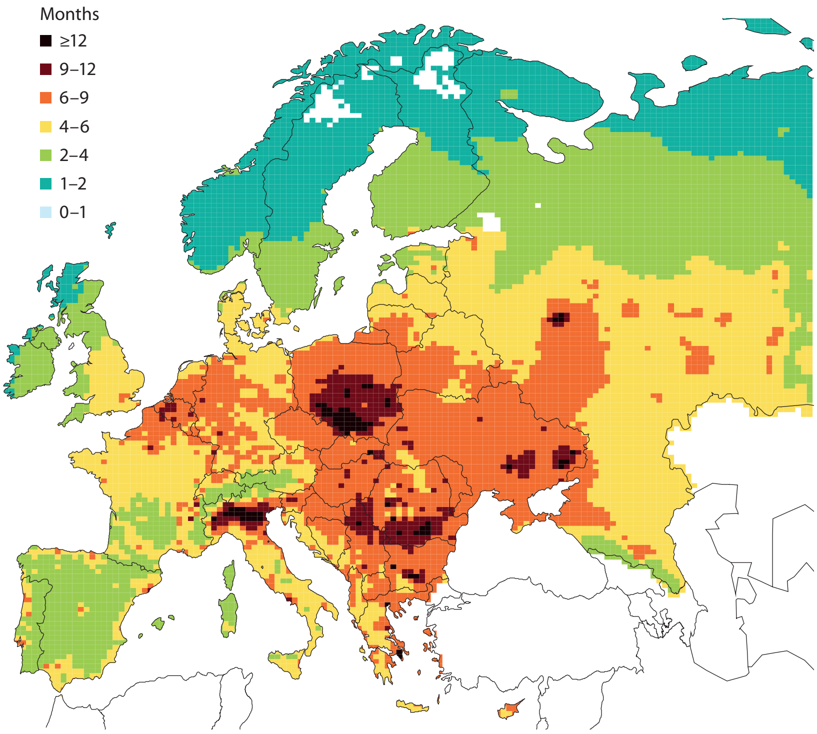
$PM_{2.5}$ Tiny solid or liquid particles less than 2.5 µm wide, including soot and aerosols formed from gaseous pollutants such as sulphur dioxide, nitrogen oxides and ammonia. Their very small size allows them to enter the air sacs deep in the lungs where they may cause adverse health effects.

CRITICAL LOAD A quantitative estimate of exposure to deposition of one or more pollutants, below which significant harmful effects on sensitive elements of the environment do not occur, according to present knowledge. Exceedance of a critical load is defined as the atmospheric deposition of the pollutant above the critical load.

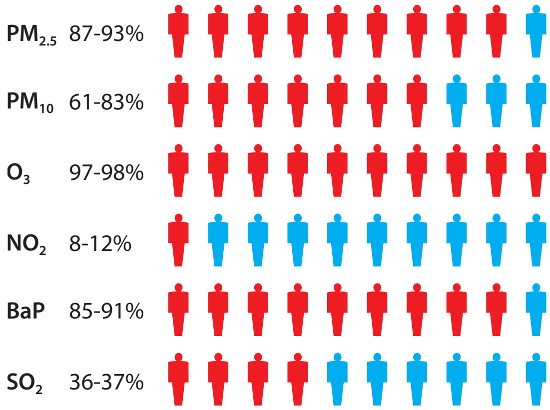
Despite successes, concerns still widespread

Although abatement measures under the Convention have seen significant success, air pollution is still the primary environmental cause of premature death in Europe. Harmful pollutants in outdoor air include particulate matter, ozone and nitrogen dioxide; diesel engine exhaust (a major source of fine particles in urban air) has been classified as carcinogenic to humans by the WHO's International Agency for Research on Cancer. Premature deaths attributable to outdoor and indoor air pollution in the UNECE region in 2012 (including North America) totalled 576,000 and 118,500, respectively.

▼ *Loss in life expectancy due to fine particulates ($PM_{2.5}$) is highest in northwestern continental Europe, eastern Europe and the Po Valley.*[vii]



▶ *The proportion of the population living in areas exceeding WHO air quality guideline values varies by pollutant, with over 87% of the EU population exposed to high levels of fine particles ($PM_{2.5}$) and 98% to high levels of ozone (O_3).*[viii]



The majority were due to cardiovascular, cerebrovascular and respiratory diseases, as well as to lung cancer. The number of premature deaths due to air pollution in the EU is ten times higher than those caused by traffic accidents.[ix]

Exposure to recent air pollution has been responsible for 1 in 20 deaths in the United States. Studies suggest that reducing exposure to fine particulate matter and ozone by 33% would avoid 43,000 premature deaths, tens of thousands of non-fatal heart attacks and respiratory and cardiovascular hospitalisations, and hundreds of thousands of acute respiratory symptoms. Around 57 million people in the United States were exposed to air quality levels above the national ambient air quality standards in 2014. Air pollution in Canada is associated with 21,000 premature deaths each year and over 28% of Canadians are exposed to outdoor levels of ground-level ozone that exceed current air quality standards. Average ozone levels in Canada decreased by 15% between 1998 and 2012.

The number of life-years lost to outdoor air pollution shows wide regional variation: the rate in Western Europe is twice that of North America and the rate in EECCA countries (including West-Balkan) is 20% higher again. Average loss in life expectancy due to fine particles is currently about 5 months in Europe but can be more than 12 months in some urban areas. A recent survey showed air pollution to be the number one environmental concern for the general public.

Heavy metals and persistent organic pollutants are known for their toxicity, and even low environmental levels may cause significant exposure over time due to their accumulation along food chains. Despite lower emissions and fewer 'hotspots' near industrial areas, long-term risk for human and environmental health still exists in many UNECE countries. For example, critical loads for mercury (a neurotoxin) are still exceeded in large parts of Europe.[x]

Acidification of soils, freshwaters and ecosystems following high levels of sulphur and nitrogen deposition across large parts of Europe and eastern North America is in decline or slowing. Successful reductions in sulphur dioxide emissions from their peak in 1980 means deposition is now much lower and some forests and lakes are showing signs of recovery. Although acidification is still an issue in many areas, the pace is much slower.

Nitrogen deposition in excess of critical loads affects plant communities, possibly favouring dominant species over protected species. This could have knock-on consequences for butterflies, other insects and birds. It could also favour plants and insects that cause allergies or disease, and could contribute to an increase in the occurrence of algal blooms.

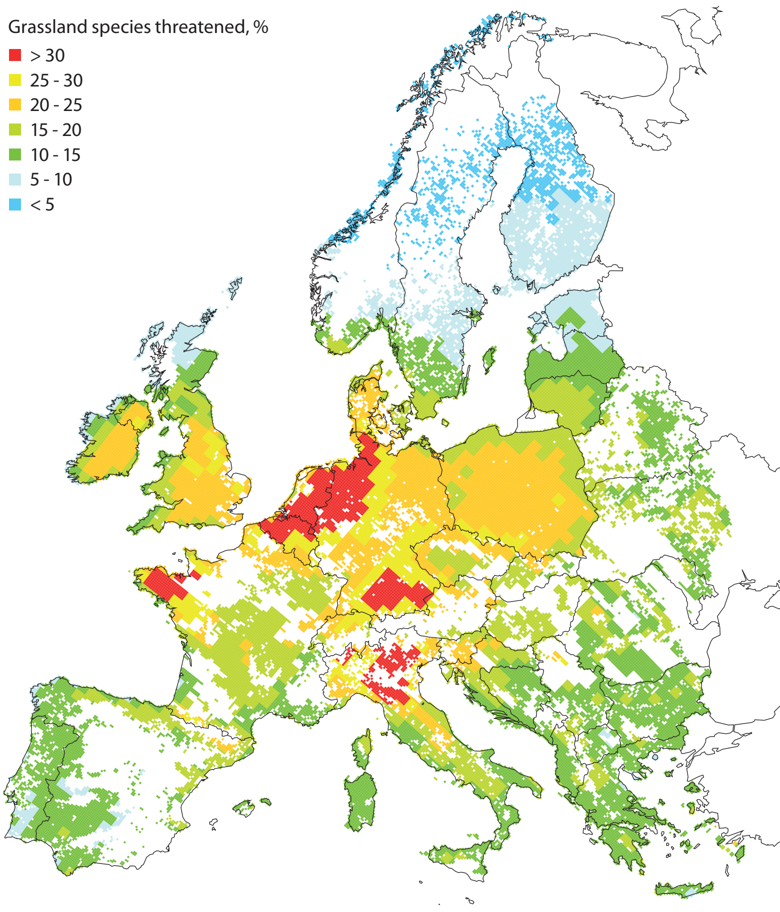
Paying the price

In financial terms, the costs of damage to human health from air pollution are greater than for the other damage categories that can be costed (such as damage to crops or buildings). Costs are also incurred through damage to ecosystems and ecosystem services but these air pollution impacts are difficult to monetise.

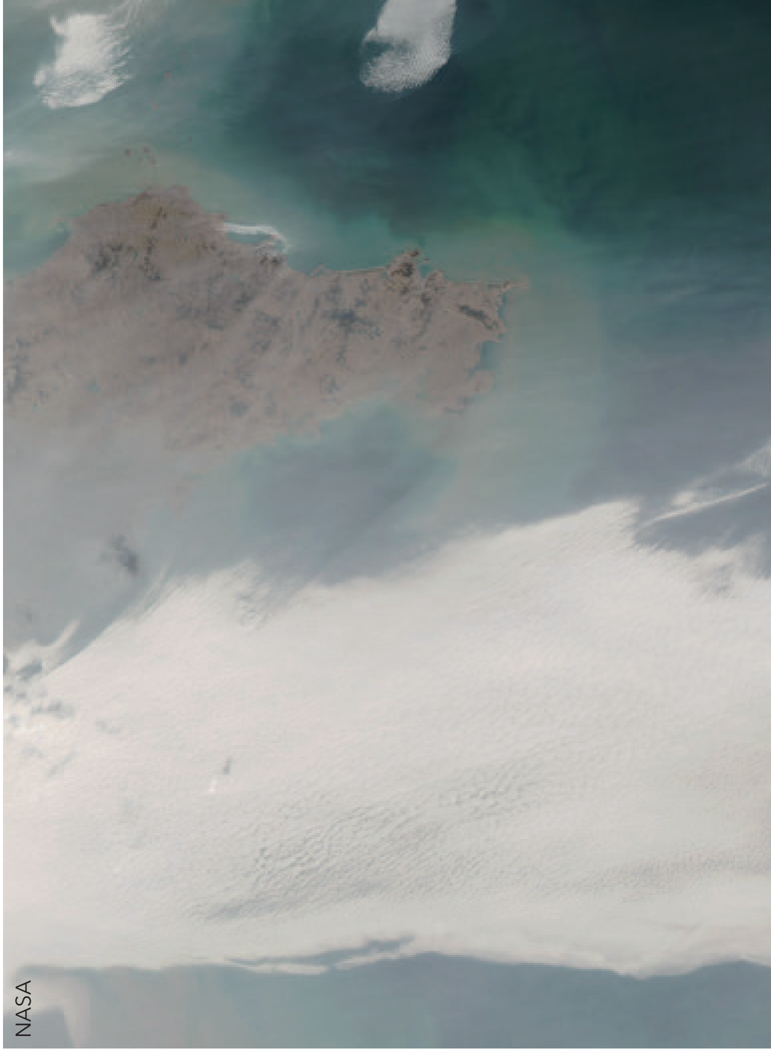
The total economic costs of premature death related to air pollution across the European UNECE region are about EUR 1 trillion, with the costs of illness due to air pollution (such as hospitalisation and medicine) adding another 10%. For half the UNECE countries, the total health costs of air pollution represent more than 10% of GDP.[xi] Air pollution also has major productivity consequences for the economy, accounting for 5–10% of sickness-related absence. In fact, for the EU28, emission reductions proposed by the European Commission in 2013 could result in cost-savings to industry through less sickness-related absence that are greater than the costs of additional air pollution abatement.

For North America, 18% of people in the United States live in counties exceeding the US air quality standards, and 28% of Canadians live in communities where ground-level ozone levels exceed air quality standards. The annual economic cost of premature deaths, heart attacks, hospital admissions, emergency department visits, and missed school work exceeds USD 1 trillion in the United States, while the annual costs of air pollution related impacts on human health in Canada are more than CAD 8 billion.

Ground-level ozone concentrations are reducing the production of crops and wood in Europe by up to 15%, depending on species sensitivity. In terms of effects on wheat production alone, the loss is valued at EUR 4.6 billion per year in Europe. Ozone could also affect future agricultural productivity through a decline in pollination. Damage to the built environment and cultural heritage in Europe is estimated at over EUR 2 billion per year.



▲ *Models suggest that the share of grassland species threatened by nitrogen deposition in 2020 under the revised Gothenburg Protocol will be greatest for regions in northwestern Europe with the most intensive agriculture.*[xii]

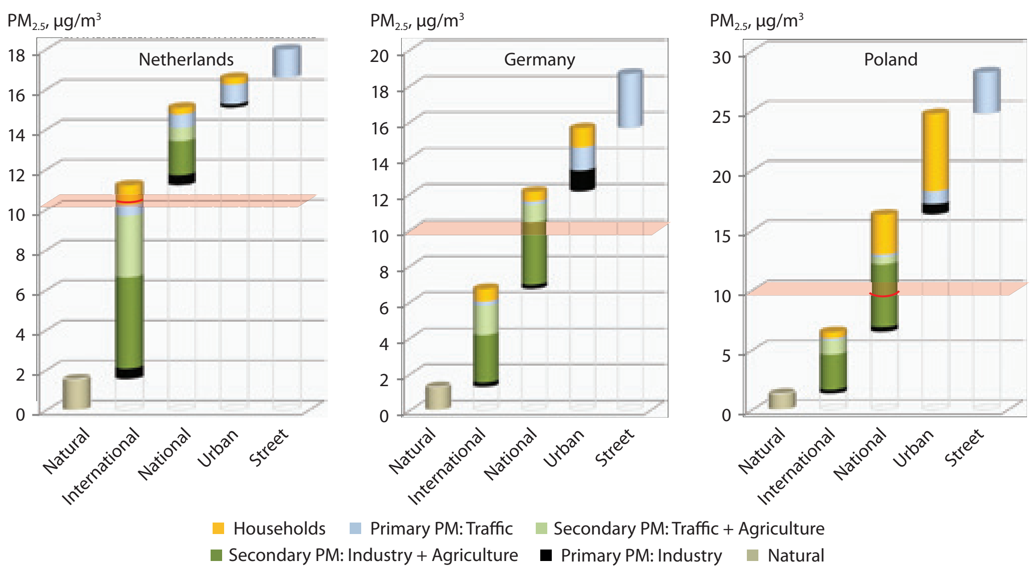


A global problem

In several parts of Europe, human exposure to fine particulate matter is largely due to ammonium-nitrate and ammonium-sulphate particles arriving via long-range transport. Known as secondary particles, they are formed in the air from precursors (ammonia, sulphur dioxide and nitrogen oxides) picked up by air masses travelling over the source regions. Ozone concentrations are also largely influenced by transboundary (even transcontinental) transport of ozone and its precursors (nitrogen oxides, volatile organic compounds and methane).

Intercontinental transport is also an increasingly important issue for mercury and some persistent organic pollutants (harmful chemicals that remain intact in the environment for long periods and achieve a wide geographical spread). As many of the local 'hotspots' have now been tackled and little improvement has been noted since significant emission reduction prior to 2005, the remaining challenge is to reduce global background levels. The global aspect was a major factor underlying the development of the Stockholm Convention on Persistent Organic Pollutants (adopted in 2001) and the Minamata Convention on Mercury (adopted in 2013).

Peak ozone exposure has declined since the 1990s (through reductions in precursors). But to protect human health, the issue is not just reducing the occasional peaks in exposure but reducing longer-term exposure to much lower levels, and background concentrations are not declining. Because emissions in other parts of the northern hemisphere contribute substantially to ozone concentrations in Europe and North America, co-ordination beyond the European and North American scale will be needed to decrease ozone levels. This is also the case for some persistent organic pollutants (e.g. hexachlorobenzene, dioxins, polychlorinated biphenyls) and mercury.



◀ Comparing the origin of fine particles at street level shows local $PM_{2.5}$ concentrations are strongly influenced by secondary particles from transboundary sources. The data are averages based on measurement sites in several cities.[xiii]

Solutions are available

Much of the reduction in air pollution has been the combined result of end-of-pipe abatement measures and structural changes in the energy, industry, transport and agricultural sectors. Coherent scenarios for climate change and air pollution policy show that future trends in air quality could benefit from climate- and energy-related measures as well as environmentally-friendly agricultural policy. Technical measures are available (for combustion facilities, vehicles, ships and farms) to meet the WHO guideline levels (or comparable ambient air quality standards) for fine particles and ozone in most places in Europe and to avoid excess nitrogen in most European nature areas. Behavioural changes in energy use, transport and diet could also play an important role. Measures are also available for heavy metals and persistent organic pollutants, and coordination with other international agreements and policy frameworks could provide further opportunities for solutions.

Benefits exceed costs

Economic models suggest the direct costs of additional measures needed to ratify the revised Gothenburg Protocol will be negligible; for EU-countries less than 0.01% of European GDP. Although jobs will be lost in some sectors (e.g. fossil fuel) they will be gained in others (e.g. building and equipment). The overall impact on employment is expected to be small. Cost-benefit analyses of abatement policies consistently show that societal benefits are substantially higher than the costs for some sectors. Over the long term, environmental policy will favour the economy through more efficient use of resources. Some economic benefits will be felt immediately, for example, the impacts of new measures on sickness-related absence.[xiv, xv]

A larger market for clean technologies will reduce production costs, in turn reducing the costs of abatement. Countries that move first in this market will maximise their possibilities for growth in a clean tech industry.

Overall, abatement costs are projected to be significantly lower than the monetised benefits achieved by improving human and ecosystem health.

Action needed at various levels

Air pollution policy is currently driven by public health concern at a range of levels – from cities to international fora.

Episodes with high levels of pollution (‘smog days’) raise public concern, cause health complaints and sometimes make air pollution literally visible. Many local initiatives are taken to develop ‘healthy’ cities. But because sources outside cities often contribute significantly to local air pollution, many European cities will be unable to meet WHO guideline levels for air pollutants by local action alone. In fact, even national and continent-wide action may not be enough in some cases (for example, to prevent ozone damage).

Acknowledging that measures within the Convention area may be insufficient to reduce background levels for many air pollutants, scientific collaboration on long-range transport at the northern hemispheric scale is currently being promoted through the CLRTAP Task Force on Hemispheric Transport of Air Pollution. This Task Force showed that further protection of health and ecosystems would require reduction of all ozone precursors, including methane.

Synergies and cooperation with other international agreements and organisations are currently being increased. For example, with the Stockholm Convention, the Minamata Convention, the Arctic Monitoring and Assessment Programme, regional seas conventions such as HELCOM and OSPAR, and the Climate and Clean Air Coalition.

MOVING TOWARDS THE WHO GUIDELINE VALUE FOR $PM_{2.5}$

The UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) focusses on setting emission targets and technical emission standards with the goal of reducing damage to health and ecosystems. The WHO Air quality guidelines provide a basis for future target setting. Reductions in particulate matter precursor emissions are essential for meeting the WHO guideline level for fine particles of 10 μg/m^3. Meeting this guideline level would reduce the average loss of life expectancy in Europe by almost 6 months relative to 2005.

Based on the climate and energy measures proposed by the EU in the context of the UN Framework Convention on Climate Change (UN FCCC) and implementation of technically available abatement measures for air pollution, WHO guideline values for fine particles could become feasible in most parts of Europe in the coming decades. Possible action for moving towards the WHO guideline for $PM_{2.5}$ is outlined here. Action would be needed at different levels.

Convention level:

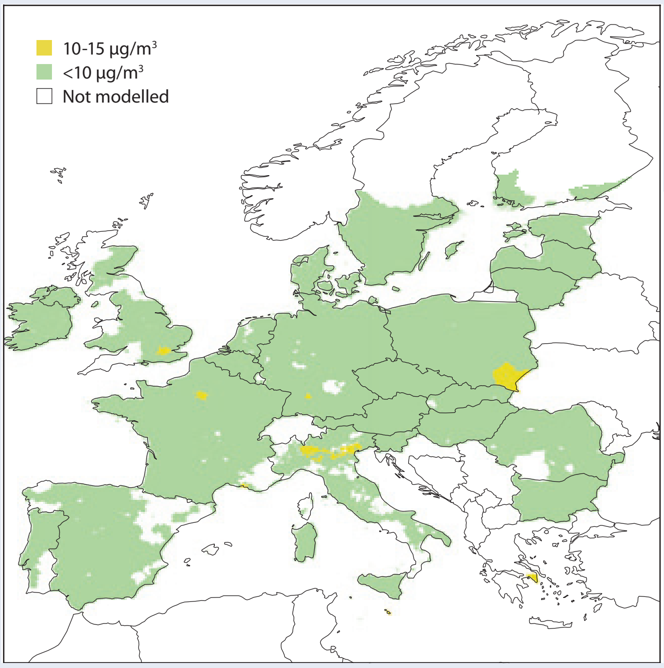
- Implement climate and energy targets
- Ensure that vehicle emission standards work in reality
- Implement emission standards for non-road mobile machinery, domestic stoves and installations for biomass burning
- Develop ammonia emission standards for large cattle farms.

National level:

- Ratify and implement CLRTAP protocols
- Implement climate and energy policies
- Implement effective control to maintenance schemes for vehicles
- Introduce scrappage schemes for old vehicles and motorcycles
- Enforce emission standards for farms and domestic stoves.

Local (urban) level:

- Introduce low emission zones to encourage early scrappage of old vehicles
- Introduce speed limits on highways near urban areas
- Encourage use of electric vehicles
- Improve infrastructure for public transport, cycling and walking
- Inform the public about air pollution from wood burning and ways to reduce pollution.



▶ *Projected $PM_{2.5}$ concentrations in 2050 after the implementation of climate and energy policies by EU countries to meet the 2°C target of the United Nations Framework Convention on Climate Change, and a shift towards low-meat diets. Only a few regions in Europe with high traffic or domestic burning of solid fuels remain likely to moderately exceed the WHO guideline.*[xvi]

Importance of an integrated approach

Air pollution policy cannot be viewed in isolation as it is closely linked to climate and energy policies, to transport and trade policies, and to agricultural and biodiversity policies. An integrated approach takes into account the co-benefits of linking climate and air policies, and the potential impacts of action in one area on another.

Most climate policy measures will contribute to cleaner air and have health and ecosystem benefits. Pollutants such as sulphur dioxide, nitrogen oxides, volatile organic compounds and fine particles ($PM_{2.5}$) largely result from the use of fossil fuels. As in past decades, future changes in the fuel mix and measures to increase energy efficiency will generally lead not just to lower carbon dioxide emissions, but also to lower emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and fine particles ($PM_{2.5}$). Reducing primary emissions of fine particles could also have co-benefits in terms of lower exposure to some heavy metals and persistent organic pollutants. Emissions of mercury and combustion-related persistent organic pollutants will also decline if less coal is used.

Measures to address climate change in isolation from the aims of air pollution abatement policies could lead to more air pollution. For example, an isolated focus on reducing carbon dioxide emissions by encouraging the use of wood stoves, diesel cars or biofuels, could result in co-damage to air quality by increasing exposure to fine particles.

Air pollution can have short-term regional climate effects. Some pollutants act as cooling agents (e.g. sulphates), while others contribute to warming (e.g. black carbon, and ozone and its precursors). To minimise additional warming due to air pollution policy, attention would be needed on the abatement of black carbon emissions, such as from diesel vehicles. The Euro-6 standards and controls on diesel vehicles and engines in North America include such an approach. Use of biomass or measures to reduce methane from agriculture are other examples where there are linkages between air pollution and climate change, and where there would be benefit from considering climate and air pollution together in order to limit adverse health effects.

According to current knowledge a warmer climate is conducive to higher ozone concentrations. To help avoid these, more effort would be required to abate ozone precursors in the northern hemisphere. This would need a co-ordinated approach that goes beyond the current domain of the LRTAP Convention and includes major emitters in South and Southeast Asia. Limiting methane emissions is of major importance for controlling ozone concentrations over the coming decades.

In Europe, future ammonia emissions are linked to changes in farming practice and developments in livestock and population diets. Current knowledge suggests that ammonia emissions would increase under a warmer climate. Ammonia-related problems such as human exposure to secondary particles (the formation of which may become more important in the future when more biogenic aerosols are released from forests owing to higher global temperatures) and biodiversity loss will not decrease due to climate policy. In Europe, some measures to reduce ammonia emissions would imply financial benefits as they include a more efficient use of nutrients within agriculture. The potential for technical options to reduce ammonia emissions is significant, but more limited than for sulphur dioxide or nitrogen oxides. Non-technical options for ammonia include reducing livestock densities in and around sensitive nature areas, reducing food waste and encouraging low-meat diets. Reducing the amount of meat in the diet would lead to less manure and lower ammonia emissions during production.

Next steps for further co-operation

By meeting current commitments through ratification and implementation of CLRTAP protocols, many Parties would see more cost-effective reductions in health and environmental impacts than could be achieved by unilateral action alone. The more Parties ratify the protocols, the larger the scale of the market for cleaner technologies, and the lower their costs. Implementation would also ensure 'a level playing field' for industry, and prevent Parties competing with each other at the expense of human and environmental health.

Incomplete and uncertain emission data may hinder ratification of the revised Gothenburg Protocol, especially by EECCA countries because 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 have already been implemented. Even for EU countries, uncertainties in the implementation of legislation can prove a challenge in meeting national emission ceilings.

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

The LRTAP Convention offers a framework for mutual learning and solution finding. Further improving emission inventories, developing better projections and harmonising the monitoring of air quality as well as health and ecosystem impacts, will strengthen assessment and modelling capabilities in support of policy progress. Exploring synergies between air pollution policy at the local, regional and hemispheric scales, as well as with energy, transport and agricultural policy could help to identify additional cost-effective measures.

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Summary for Policymakers – Endnotes

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ii TFMM, 2016. Air Pollution Trends in the EMEP region between 1990 and 2012, Task Force on Measurement and Modelling (TFMM), European Monitoring and Evaluation Programme (EMEP), CLRTAP

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Scientific Assessment Report 2016

1. Health impacts of air pollution

Emission reduction has led to a decrease in particulate matter concentrations in air in Europe of about 30% at European Monitoring and Evaluation Programme (EMEP) measurement sites over the period 2002–2012, corresponding with reduced population exposure and an increase in average life expectancy in Europe of almost 3.5 months between 2000 and 2010. But even in 2012, almost 600,000 premature deaths related to ambient air pollution were estimated to have occurred in Europe and high-income North America (WHO, 2014). Most resulted from exposure to particulate matter (PM).

Based on current knowledge, health effects have been calculated for exposure to small PM (PM_{10}: ≤ 10μm in diameter) or fine PM ($PM_{2.5}$: ≤ 2.5μm in diameter) both of which cause cardiovascular, cerebrovascular and respiratory diseases, 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 observed health effects or to act as a proxy for the mix of pollutants responsible for the observed health effects (WHO Regional Office for Europe, 2013a).

In 2005, $PM_{2.5}$ concentrations were estimated to lead to an average loss in life expectancy for Europe of 8.3 months. In many cities, loss in life expectancy from air pollution remains significantly higher than this average. In some areas such as Eastern Europe, the Caucasus and Central Asia (EECCA), more monitoring is required to quantify the impacts to health from air pollution.

In North America, ambient concentrations of $PM_{2.5}$ have declined significantly. Between 2000 and 2012, the US average annual concentration of $PM_{2.5}$ decreased by 33%. In Canada, the average annual $PM_{2.5}$ concentration decreased by 4% over this period. However, between 2003 and 2012, the percentage of Canadians living in communities where ambient concentrations of $PM_{2.5}$ exceeded established air quality standards dropped from about 40% to 11%. In 2012, ambient concentrations reported at most monitoring sites in the United States along the Canadian border met the annual National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ set in 2012. In addition, although significantly reduced in most border areas, $PM_{2.5}$ continues to contribute to visibility impairment in the United States and Canada, particularly in highly populated regions of southern Ontario and Quebec in Canada and the Midwest and Montana in the United States (US EPA and ECCC, 2016).

1.1 Air pollution is a major threat to health

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 ranked ambient particulate air pollution as the ninth cause of disease burden globally for 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 as a 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.

Exposure to air pollutants such as PM and ozone (O_3) is an ongoing threat to public health. Increased monitoring coverage of population exposure to air pollution, especially for $PM_{2.5}$ has led to improvements in estimating population exposure. Around 75% of the population of European cities for which PM data exist is exposed to annual PM_{10} concentrations that exceed the World Health Organization (WHO) air quality guideline concentrations (WHO Regional Office for Europe, 2006; EEA, 2015a). Although this proportion remains high, there have been improvements compared to previous years, with average PM_{10} concentrations decreasing in most countries over the past decade (Fig. 1) (EEA, 2015b; WHO Regional Office for Europe, 2015; TFMM, 2016).

In order to protect health the WHO has formulated scientifically-based air quality guideline values that can be used by countries as long-term targets on a voluntary basis. Based on the latest science and including the WHO guidelines, the European Union (EU), the United States, Canada and other countries have each put in place air quality standards that also take into consideration a number of other factors. The values for these air quality standards are reviewed and updated as appropriate, on a regular basis.

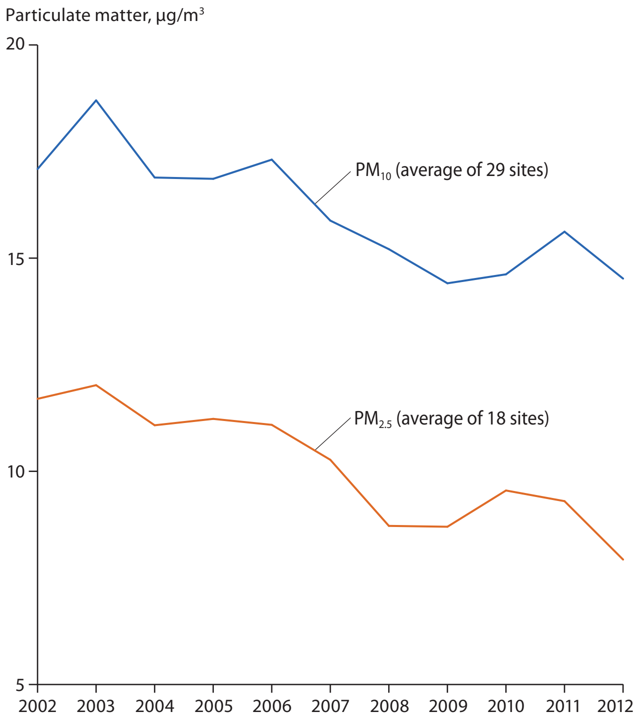


Figure 1. Trends in observed annual average concentration of PM_{10} and $PM_{2.5}$ at EMEP sites (TFMM, 2016).

The WHO recently reviewed current understanding of the science underlying human health impacts 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 become increasingly evident in recent years due to research findings strengthening the existing, already strong evidence for human health effects of ambient air pollutants such as PM, O_3 and nitrogen dioxide (NO_2), particularly for the specific effects of NO_2 and the effects of long-term low exposure to O_3.

In the EU the health impacts of PM, the main cause of death from air pollution, were reduced by approximately 20% between 2000 and 2010 (EC, 2013). Health effect estimates in North America are shown in Box 1.

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 reducing long-term $PM_{2.5}$ concentrations to the WHO air quality guideline concentration could extend average life expectancy in the most polluted cities in Europe by about 20 months (Fig. 2).

1.2 International attention on air quality and health is increasing

In 2012, the CLRTAP Executive Body adopted amendments to the 1999 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 ($PM_{2.5}$). Black carbon is also included in the revision as an important component of $PM_{2.5}$ (UNECE, 2015). The revised protocol has not yet entered into force as it is still awaiting sufficient ratifications.

Box 1. Health effect estimates in North America

Scientists at the United States Environmental Protection Agency (US EPA) have evaluated the evidence for health effects associated with exposure to various $PM_{2.5}$ components. Many of the different chemical components of $PM_{2.5}$, as well as combinations of components associated with specific $PM_{2.5}$ sources, have been linked with adverse health effects. In the 2012 review of the $PM_{2.5}$ NAAQS, the US EPA concluded that available evidence is not sufficient to identify those components or sources that are most closely related to adverse health outcomes, and that $PM_{2.5}$ remains the most appropriate indicator of health effects associated with fine particle exposures (US EPA, 2012).

The 2012 Canadian Smog Science Assessment (Government of Canada, 2012) concluded that all Canadians are at some risk from the effects of ongoing exposure to air pollution, particularly PM, and noted a heightened level of sensitivity for those with cardiovascular and respiratory diseases. This is important due to the prevalence of such diseases in the Canadian population, where cardiovascular disease accounts for 30% of mortality and respiratory disease for another 10%. Asthma, which is exacerbated by PM and O_3, has been diagnosed in at least 8% of the Canadian population over 12 years in age. Diabetes, a common and increasing disease currently affecting 10% of Canadians, is adversely affected by smog.

In response, both countries have lowered their ambient air quality standards to protect human and ecosystem health from the harmful effects of $PM_{2.5}$. In December 2012, the US EPA strengthened the annual health NAAQS for $PM_{2.5}$ to 12 µg/m³. In May 2013, Canada established new more stringent Canadian Ambient Air Quality Standards for annual $PM_{2.5}$ of 10 µg/m³ in 2015 and 8.8 µg/m³ in 2020. The 2020 standards for $PM_{2.5}$ will be reviewed in 2017.

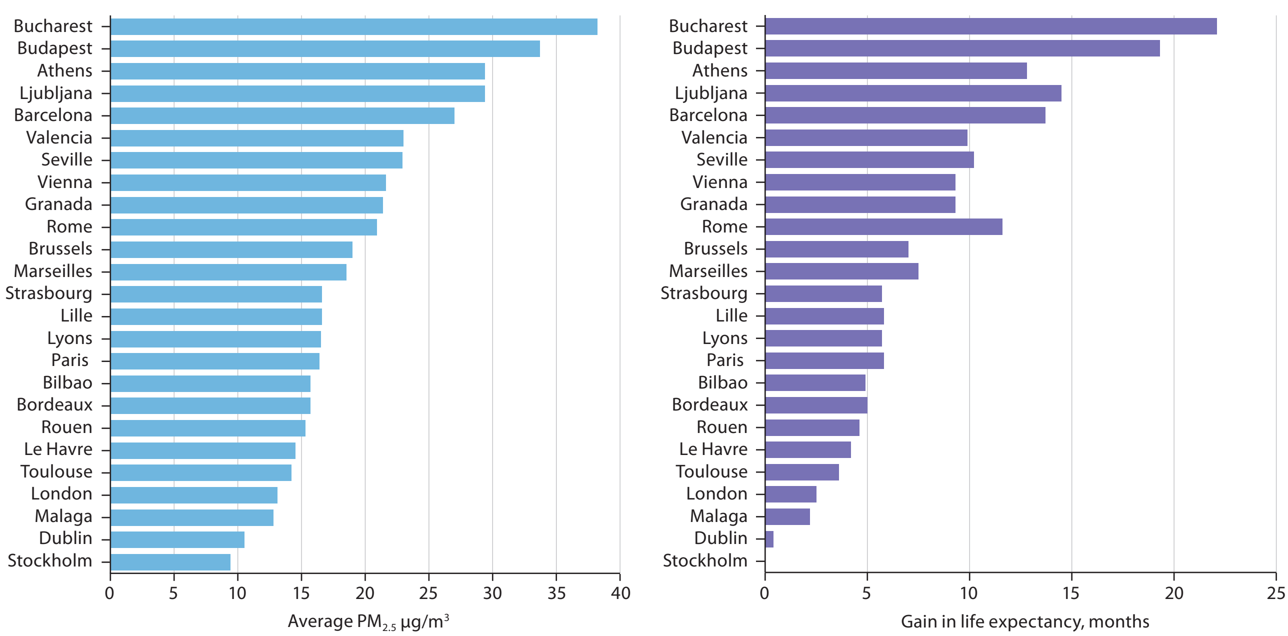


Figure 2. Projected gain in average life expectancy for people aged 30 years by reducing annual average $PM_{2.5}$ concentrations in the 25 European cities participating in the Aphekom project to the WHO air quality guideline concentration of 10 µg/m³ (based on Aphekom, 2011).

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

Air pollution is among the top ten causes of death and disease globally. Therefore the WHO, the Organisation for Economic Co-operation and Development (OECD), the EU and the United Nations Environment Programme (UNEP) have placed 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 national and international bodies could further stimulate air pollution policy.

Ambient air pollution is considered the most important environmental risk factor for health and as such deserves particular attention. In addition to efforts under CLRTAP, action has also been taken by other international organisations:

- In the Parma Declaration of 2010, Ministers of Health and Environment of the WHO European Region committed to reduce exposure to air pollution, decrease diseases, and take advantage of the approach and provisions of the CLRTAP 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 support to Member States to amplify the health sector's ability to protect and improve public health.
- In 2014, the UN Environment Assembly called for strengthening actions on air quality. 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 health and the economy, and to contribute to meeting the sustainable development goals in 2030 (WHO, 2015).
- UNEP hosts the Secretariat of the Climate and Clean Air Coalition (CCAC), a global effort created to raise awareness, enhance and develop actions, promote best practices, and improve scientific understanding of the short-lived climate pollutants (SLCPs) ground-level ozone, methane (CH_4), black carbon and hydrofluorocarbons.
- Under the Canada–US Air Quality Agreement (AQA), the United States and Canada have committed to address transboundary O_3 by reducing emissions of nitrogen oxides (NO_X) and volatile organic compounds (VOCs); precursors to O_3. The commitments apply to a defined region in both countries. Collaboration to date has led to significant reductions. Between 2000 and 2012, total NO_X emissions in the AQA region of Canada decreased by 45% and in the AQA region of the United States by 47%. Emissions are projected to continue to decline through to 2025.

1.3 Progress in policy development

Cost-effective interventions are available that reduce air pollution and lead to health benefits (WHO Regional Office for Europe, 2013b). Consistent scientific evidence shows that lowering air pollution levels results in health benefits for the population, and that these improvements occur relatively quickly after the reduction in pollution, possibly after as little as a year (Laden et al., 2006; Lepeule et al., 2012). To date, regulatory efforts have led to reduced emissions of some key air pollutants in Europe and North America (EEA, 2015b), which may lead to reduced population exposure and a reduced burden of disease.

Reductions in primary PM, sulphur, NO_X 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 (Kiesewetter and Amann, 2014; Lelieveld et al., 2015). Further control measures on emissions of nitrogen compounds, especially ammonia would be cost-effective for human health benefits and would reduce critical-load exceedance for nitrogen deposition (Amann, 2014).

Air pollution related health impacts are linked to emissions from various sectors, such as industry, transport, power and heat generation, and agriculture. The World Health Assembly called upon the health sector to engage with a range of other sectors in order to provide policy options that will yield the greatest benefits to health. Furthermore, air pollutants can travel thousands of kilometres, crossing national borders, oceans and continental land masses. 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. CLRTAP can play a crucial role in stimulating air pollution policy and fostering cooperation at international level across Europe and North America, and possibly even beyond.

Compelling scientific evidence and the significant burden of disease from air pollution highlight the necessity for further action in all relevant sectors, to reduce emissions and as a result, improve air quality and public health.

2. Nitrogen and biodiversity

2.1 Large deterioration in biodiversity in Europe

Emissions of NO_X and ammonia (NH_3) and the subsequent deposition of nitrogen (N) caused significant changes in European ecosystems through the 20th century. Low fertility heathlands were converted to grasslands and many rare plant species adapted to low nitrogen availability disappeared. In large parts of Europe the loss of biodiversity due to excess nitrogen is still ongoing, especially in areas with a high density of livestock and thus high NH_3 deposition. Monitoring of natural ecosystems and experimental studies show nutrient imbalances, declining biodiversity and elevated nitrate leaching (Sutton et al., 2011). Figure 3 shows the decline in species richness in acid grassland with increasing N-deposition in the Atlantic region of Europe, indicating a 50% reduction in species richness as N-deposition increases by 30 kg/ha annually (Stevens et al., 2010).

CLRTAP protocols have been formulated to maximise the environmental benefits of measures to reduce emissions of nitrogen and sulphur. The approach is based on the use of critical loads (Box 2) for eutrophication, acidification and the effects of O_3 on ecosystems.

Deposition of nitrogen compounds exceeds the critical loads over large parts of Europe. Although NO_X emissions reduced by more than 40% between 1990 and 2010 and NH_3 emissions by almost 30%, the area in which critical loads are exceeded shows little change (Hettelingh et al., 2015).

Nitrogen oxide emissions from combustion sources in Europe are now roughly half what they were at their peaks around 1990, while emissions of NH_3 from agriculture have declined by a quarter. The decline in NO_X emissions is also reflected in measured concentrations of oxidised nitrogen compounds in the atmosphere and precipitation (Fig. 4). Significant declines have also been observed for ammonium in air and precipitation in line with emission trends (Fig. 5).

Box 2. 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 "*A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specific 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 for mapping critical loads as well as the geographical resolution have been improved by new scientific findings as well as improved resolution in modelling and mapping.

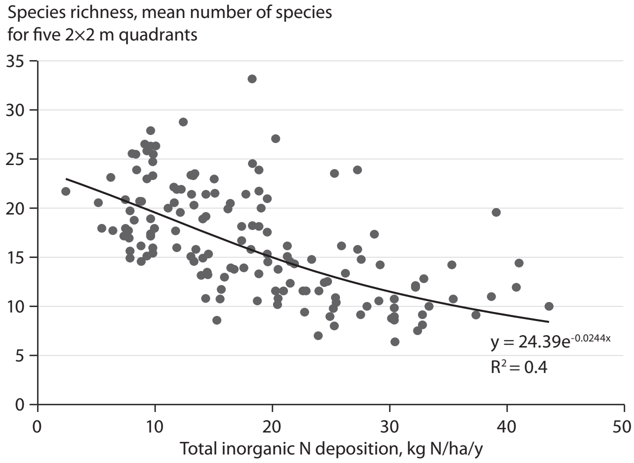


Figure 3. Relationship between species richness of acid grasslands in the Atlantic region and nitrogen deposition (Stevens et al., 2010).

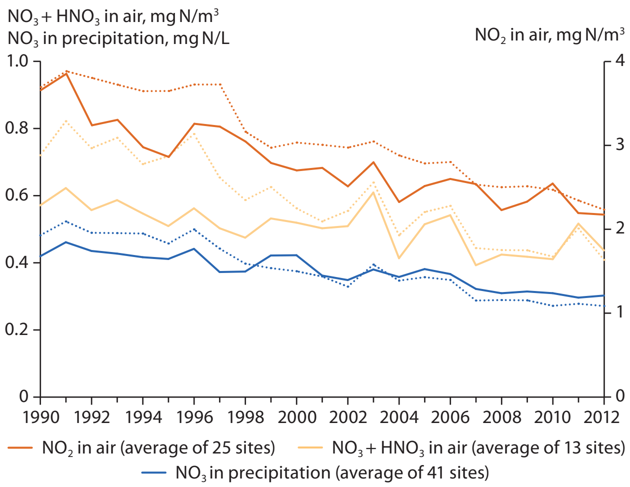


Figure 4. Observed and simulated annual average concentration of oxidised nitrogen components in precipitation and air at EMEP sites with measurements for at least 75% of the period 1990–2012. Dotted lines are model results. Data from CCC/MSC-W.

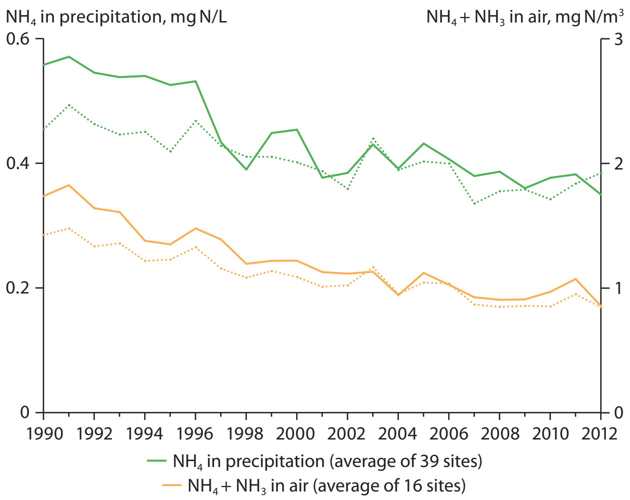


Figure 5. Observed and simulated annual average concentrations of reduced nitrogen components in precipitation and air at EMEP sites with measurements for at least 75% of the period 1990–2012. Dotted lines are model results. Data from CCC/MSC-W.

In North America, there were major reductions in wet nitrate deposition between 1990 and 2012, when large NO_X emission reductions occurred in the United States and, to a lesser degree, Canada. In the former, NO_X emissions from all sources declined from about 22.7 million tons in 1990 to 12.3 million tons in 2012, while emissions in the latter fell 32% between 2000 and 2014.

2.2 Reduction of ammonia emissions is lagging behind

The present controls agreed within the 1999 Gothenburg Protocol and its revision will further reduce N-deposition, but there is no evidence of ecosystem recovery from reduced emissions to date and it is unclear how long it will take for ecosystems to respond to the reduced N-deposition. 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 NH_3 emissions are lacking. The trend in areas at risk of eutrophication between 1980 and 2030 (Fig. 6) shows that the risk of eutrophication is persistent. The area at risk is projected to decrease from 75% in 1980 (80% in the EU28) to about 55% in 2020. The total amount of exceedances also decreases. Reduction to about 49% under MTFR2030 is technically feasible for 2030 (Hettelingh et al., 2015).

Deposition of nitrogen is also a driver for acidification and its role in relation to sulphur has increased due to the successful control of sulphur emissions. NO_X and NH_3 also contribute to the formation of particles and may be responsible for a significant proportion of the $PM_{2.5}$ concentrations in Europe and North America. NO_X from diesel cars is increasingly emitted as NO_2. This increases health impacts close to busy roads. NO_X is also a key precursor for the formation of photochemical oxidants, in particular O_3.

The global nitrogen cycle has changed substantially over recent decades. Of the total annual fixation of atmospheric nitrogen of 413 Tg-N (million tons), 51% results directly from human activity. Scenarios for the period to 2100 indicate that nitrogen will be an increasing threat to human health, ecosystems and climate. The nitrogen cycle is very sensitive to changes in climate (Fig. 7), with substantial increases projected in emissions as the climate warms in the coming decades (Fowler et al., 2015).

Further control measures on emissions of nitrogen compounds, especially those for NH_3 would be cost effective for human health benefits and would reduce exceedances of critical loads for N. Reductions in sulphur and VOC emissions achieved to date have contributed to a reduction in atmospheric PM concentrations, but this has also increased the relative contribution of nitrogen emissions to the human health effects of PM.

Thus the overall message 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 from eutrophication and that further reductions are necessary. Furthermore, the relative contribution of nitrogen compounds

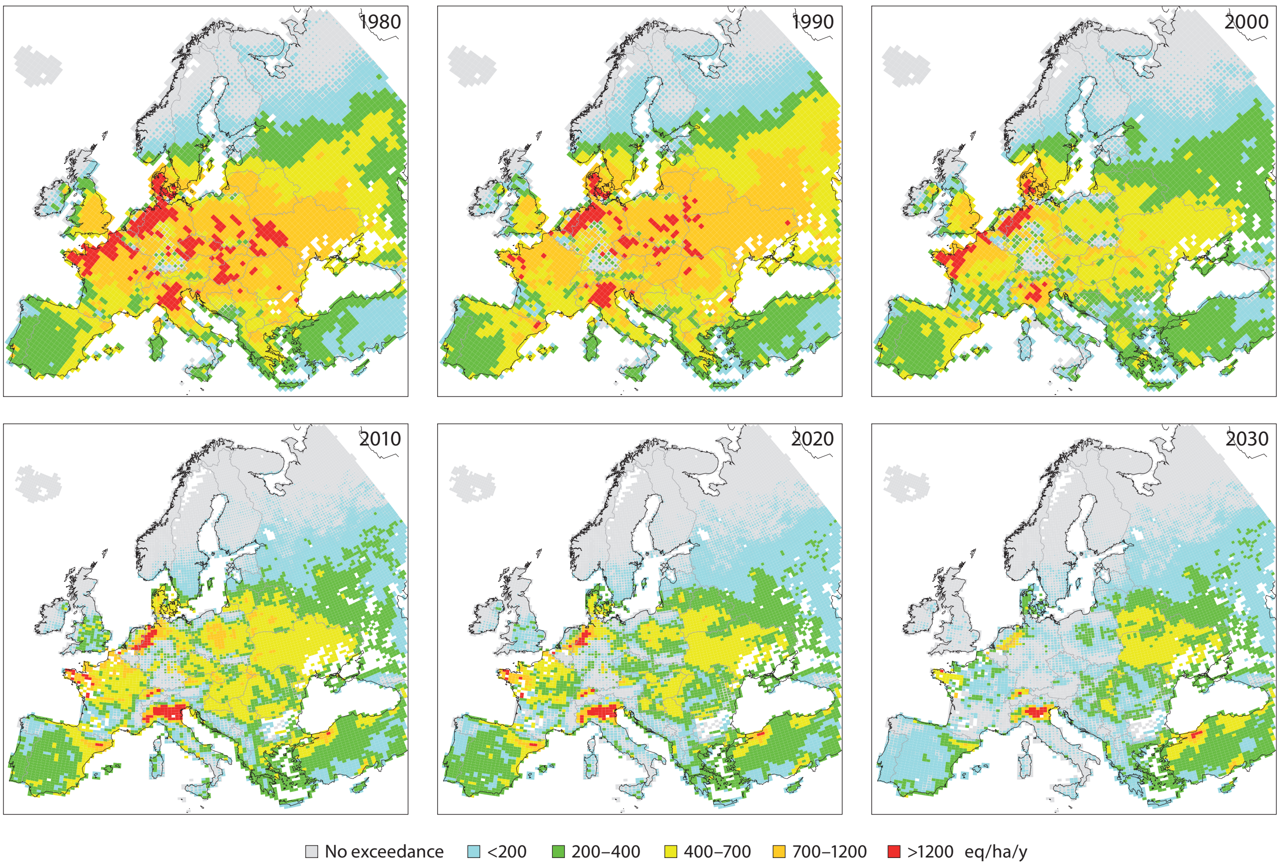
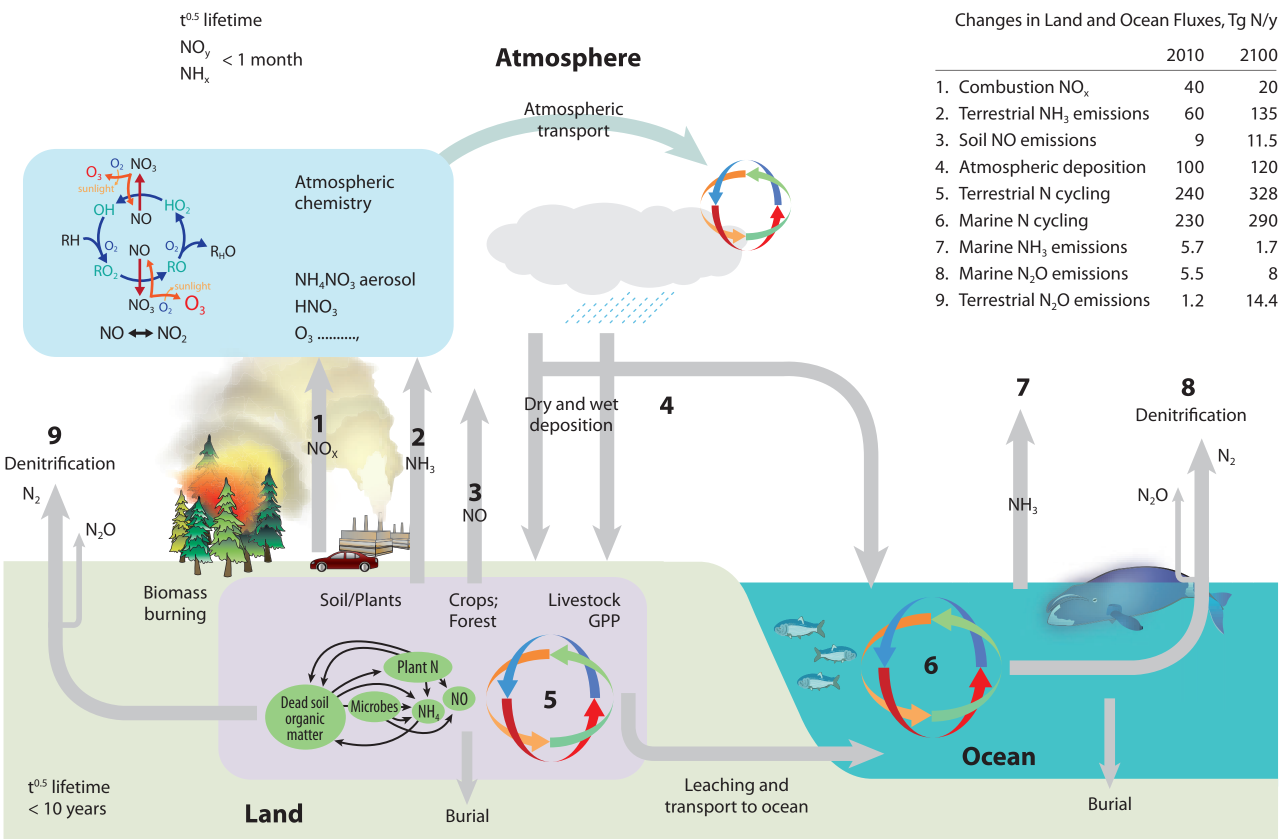


Figure 6. Average accumulated exceedance (AAE) of computed critical loads for eutrophication for 1980 to 2020 under the revised Gothenburg Protocol emission reduction agreements (GP-CLE scenario) and in 2030 under Maximum Feasible Reductions (Hettelingh et al., 2015).



Changes in Land and Ocean Fluxes, Tg N/y

	2010	2100
1. Combustion NO_x	40	20
2. Terrestrial NH_3 emissions	60	135
3. Soil NO emissions	9	11.5
4. Atmospheric deposition	100	120
5. Terrestrial N cycling	240	328
6. Marine N cycling	230	290
7. Marine NH_3 emissions	5.7	1.7
8. Marine N_2O emissions	5.5	8
9. Terrestrial N_2O emissions	1.2	14.4

Figure 7. Changes in the biogeochemical cycling of reactive nitrogen (N) between 2010 and 2100 (Fowler et al., 2015) (1 Tg = 1 million tons).

to PM has increased 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 are now a priority in Europe, both nationally and for the inter-country exchange of pollutants. Lastly the effects of climate change on emissions of nitrogen compounds may substantially offset reductions in emissions to date and new measures to reduce emissions now could avoid much larger costs later.

3. Acidification of lakes and forest soils

3.1 Acid deposition started transboundary air policy

European emissions of sulphur have been reduced by 80% since their peak in 1980. Although recovery is ongoing the acidification issue has not yet been resolved.

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 and substantial damage to materials, including historic buildings and cultural monuments was 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.

The first international agreement to reduce 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 S-deposition had decreased by nearly 90% in Europe relative to 1980 (Fig. 8).

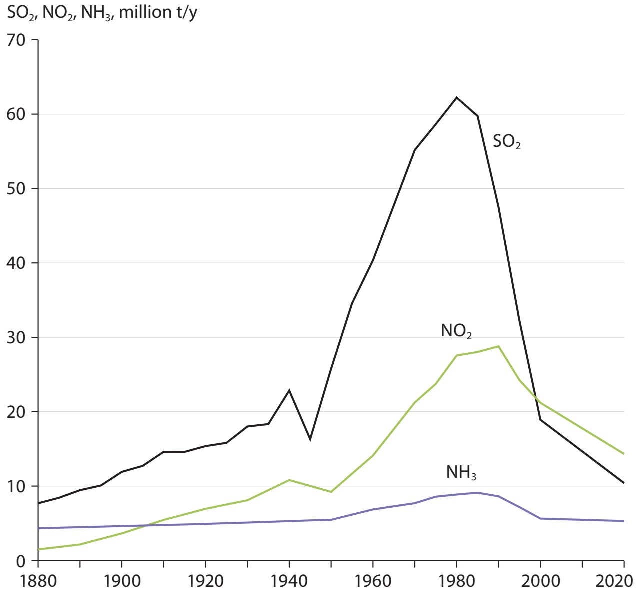


Figure 8. Emissions of European sulphur dioxide showing the progressive decline in emissions resulting from the succession of UNECE LRTAP protocols 1983, 1987, 1991, 1998, 1999. European emissions of oxidised nitrogen and reduced nitrogen are also shown. Data for 2000 are based on national inventories. Data for 2020 are from the 2010 baseline scenario. Earlier data are from Schöpp et al. (2003).

3.2 Recovery of damaged ecosystems

Lakes and streams are now recovering. Exceedance of critical loads for acidification has decreased substantially and significant exceedance is only observed in limited parts of Europe. Exceedance of critical loads has also decreased in North America. In many areas acidified soils have started to recover. Water quality is improving as shown by increased pH and buffering capacity (acid neutralising capacity; Garmo et al., 2014), and recovery of acid-sensitive sediment-dwelling insects and snails is underway. 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 (see example in Fig. 9). The same measures are responsible for the recovery of fish populations in lakes. Norway spends

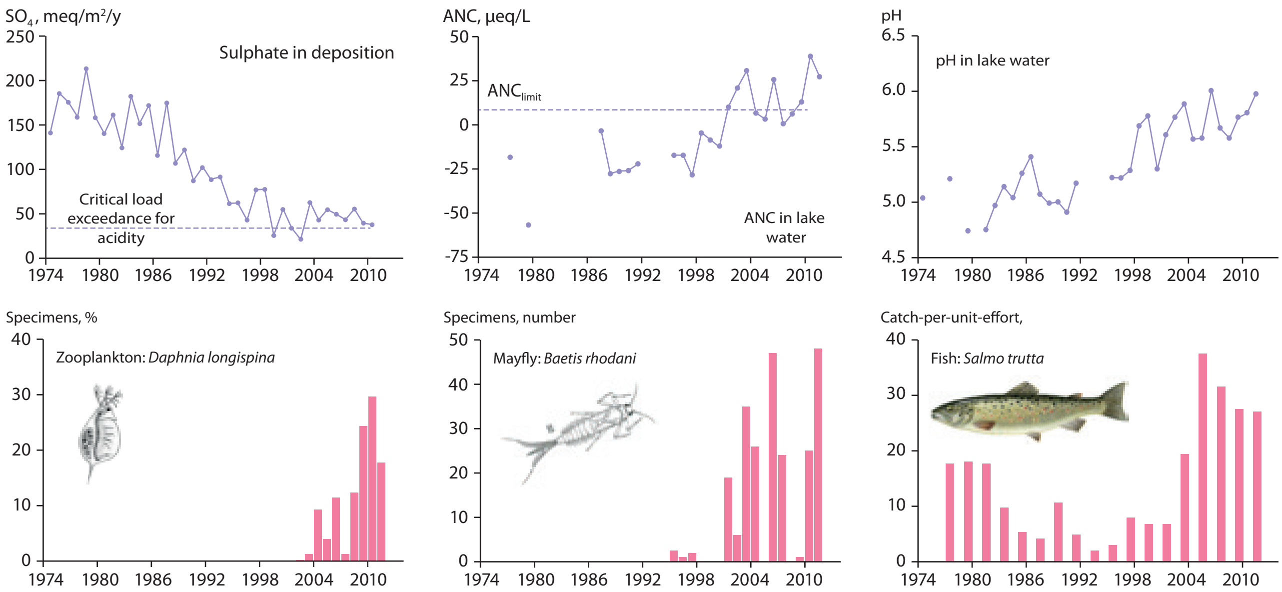


Figure 9. Recovery from acidification at Lake Saudlandsvatn, Norway. As sulphur deposition has decreased, so the acid neutralising capacity (ANC) and pH of the lake water have increased, and the populations of three sensitive species have begun to recover (modified from Hesthagen et al., 2011).

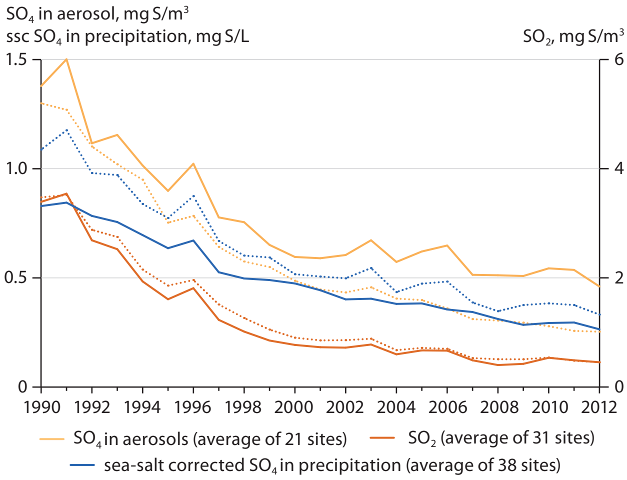


Figure 10. Observed and simulated annual average concentration in sulphur components in precipitation and air at EMEP sites with measurements for at least 75% of the period 1990–2012 (data from CCC/MSC-W).

more than EUR 10 million each year on liming surface waters. However, soil and surface water acidification remain an issue in the most sensitive areas of Nordic countries, the UK and central Europe. Recovery of acidified soils and waters will take decades to centuries, because of depleted base cations in soils, which recover through the slow process of mineral weathering. Further reductions in nitrogen and sulphur emissions will improve the situation and shorten the time for recovery.

Emission reductions in Europe over the last 25 years have resulted in a corresponding decrease in atmospheric concentrations and deposition (Fig. 10). The decline between 1990 and 2012 has been greater for SO_2 (92%) than for particulate sulphate (65%) and for sulphate concentrations in precipitation (73%). The graphic also shows good agreement between observed and simulated concentrations of sulphur in air and precipitation, with the exception of sulphate in precipitation in 1990.

The reductions in emissions have resulted in substantial improvements in freshwater and terrestrial ecosystems. The strongest evidence that emission control programmes are having their intended effect is from long-term records from lakes and streams (Garmo et al., 2014). Sulphate concentrations have decreased and acidity has declined (Fig. 11), and waters are now more suitable for fish populations.

In Canada, there was a marked reduction in emissions of SO_2 (63%) and NO_X (33%) in the period 1990 to 2014. In the United States, SO_2 and NO_X were reduced by 79% and 51% over this period (Fig. 12).

Reductions in the United States, particularly for SO_2 emissions are largely due to efforts to control power sector emissions. For example, the Acid Rain Program (ARP), established under Title IV of the 1990 Clean Air Act (CAA) Amendments, requires major emission reductions of SO_2 and NO_X, the primary precursors of acid rain, from the power sector. In addition, the Clean Air Interstate Rule (CAIR) requires emission reductions in NO_X and SO_2. In Canada, SO_2 reductions have been achieved through various actions, including the requirements to reduce the sulphur content of fuels and implementation of the Canada-Wide Acid Rain Strategy for Post-2000. At the sector level, large reductions in SO_2 emissions are attributable to technological and process changes and facility closures in the non-ferrous mining and smelting industries, the phase-out of coal-fired electricity generation in Ontario, and better emission control technologies in the upstream oil and gas sector.

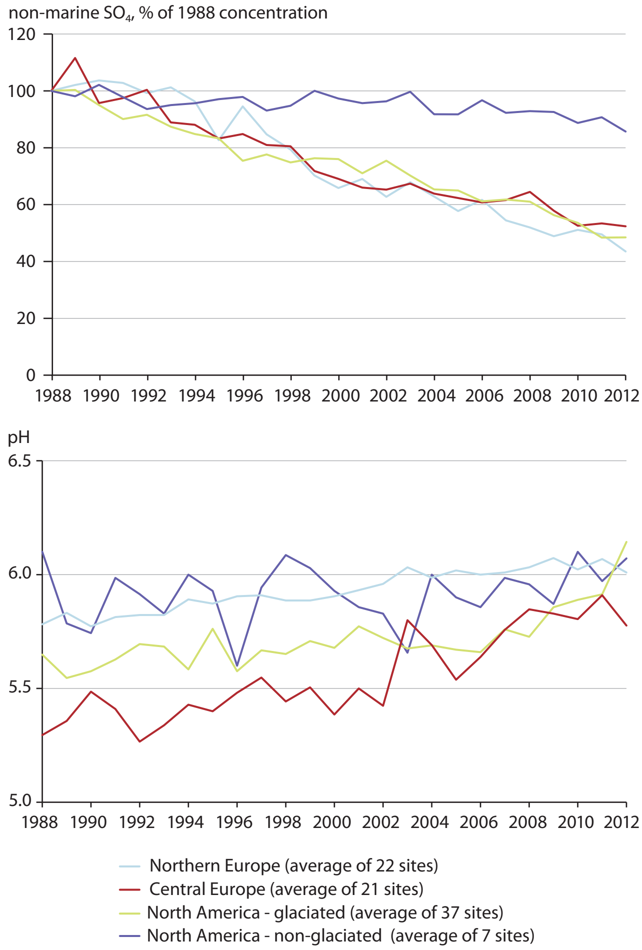


Figure 11. Trends in surface water chemistry at ICP Waters sites in Europe and North America since the late 1980s. Source: Garmo et al. (2014) and De Wit et al. (2015).

The significant reductions in SO_2 and NO_X emissions achieved in North America have reduced ecosystem acidification and improved air quality. Figure 13 shows the spatial patterns of wet sulphate (sea salt-corrected) deposition in North America for 1990 and 2012.

Wet sulphate deposition is consistently highest in eastern North America around the lower Great Lakes, with a gradient following a southwest to northeast axis running from the

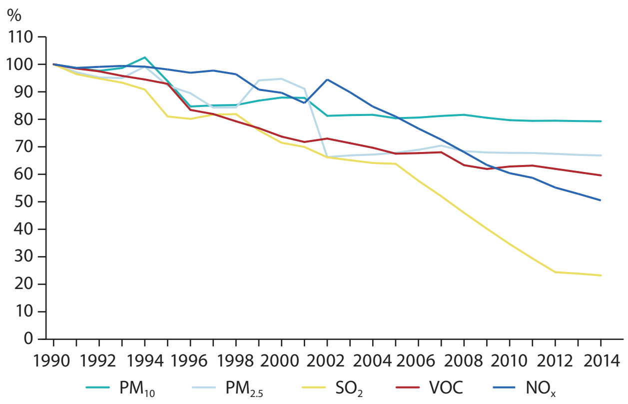


Figure 12. Change in emission of key pollutants in North America since 1990 (US EPA and ECCC, 2016).

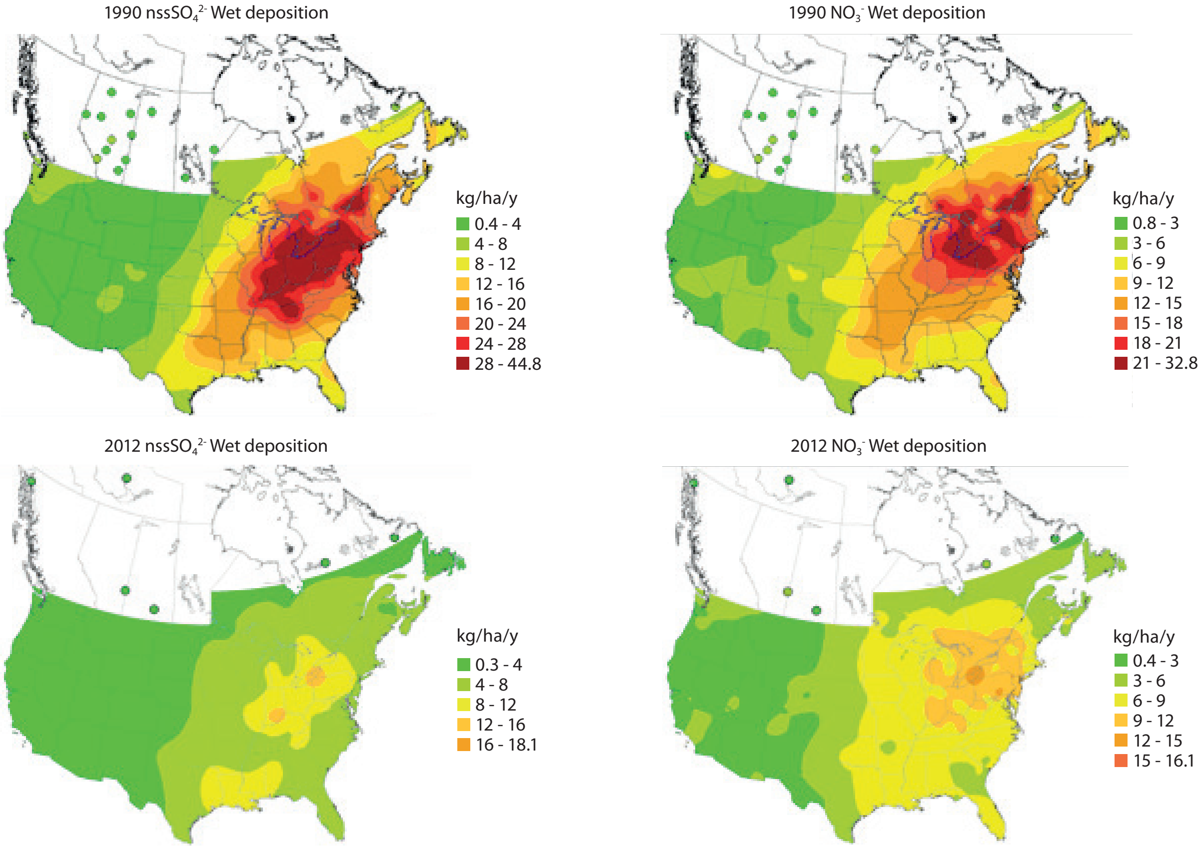


Figure 13. Changes in annual wet sulphate and nitrate deposition between 1990 and 2012 (sulphate corrected for sea salt). Deposition contours are not shown for western and northern Canada, due to the paucity of measurement sites. For these areas wet deposition values are shown as coloured circles at the locations of the measurement sites (US EPA and ECCC, 2016).

confluence of the Mississippi and Ohio rivers through the lower Great Lakes. The spatial patterns for 1990, 2000 and 2012 show that wet sulphate deposition in both the eastern United States and eastern Canada has decreased in response to declining SO_2 emissions. The wet sulphate deposition reductions are considered to be a direct consequence of decreased SO_2 emissions in the United States and Canada.

Wet nitrate deposition shows a similar southwest-to-northeast gradient, although the area of highest nitrate deposition is slightly north of the region with the highest sulphate deposition.

The trend between 1980 and 2030 for European ecosystem areas where critical loads for acidification are exceeded (Fig. 14) illustrates the decrease in the area at risk. The area at risk reduced from about 30% in 1980 to about 2% in 2020 under the revised Gothenburg Protocol and including the implementation of current legislation. A further decrease to 1% could be achieved in 2030 under Maximum Feasible Reductions (Hettelingh et al., 2015).

Inventories of critical loads and their exceedance in North America show the same patterns as for Europe in that the area

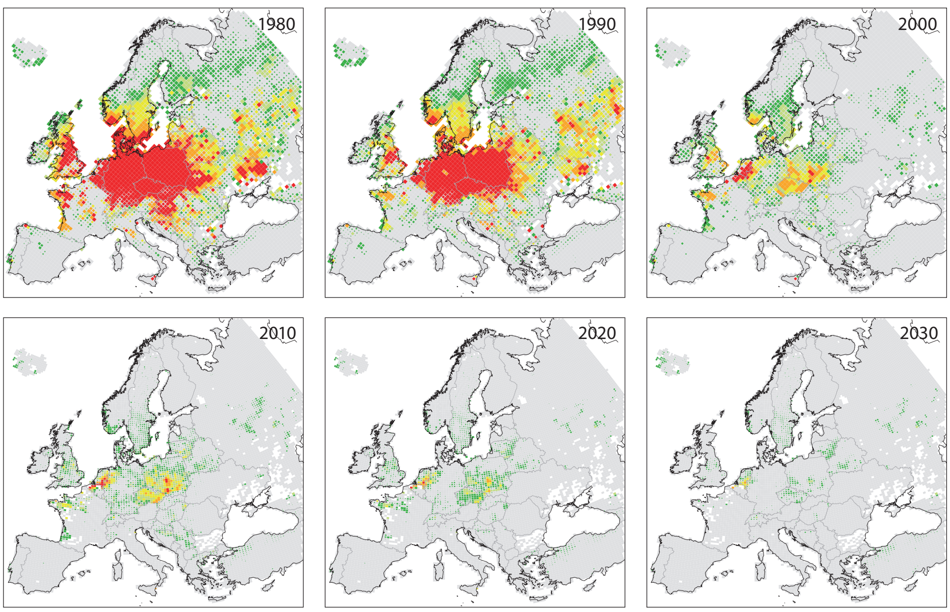


Figure 14. Average accumulated exceedance (AAE) of computed critical loads for acidification for 1980 to 2020 under the revised Gothenburg Protocol emission reduction agreements (GP-CLE scenario) and in 2030 under Maximum Feasible Reductions (Hettelingh et al., 2015).

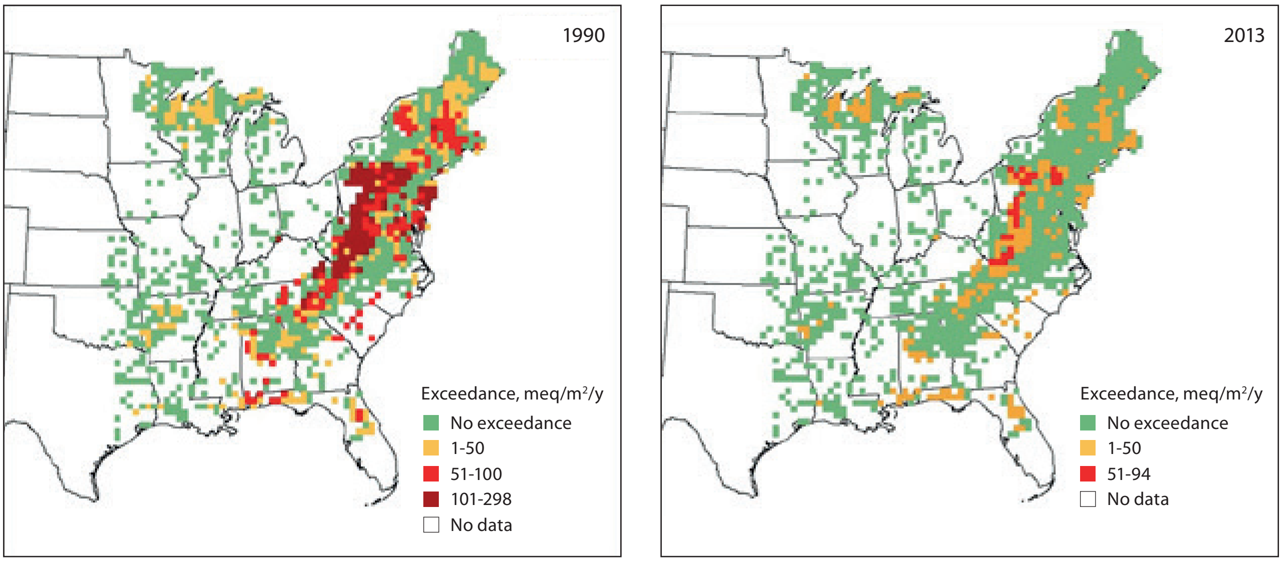


Figure 15. Lake and stream exceedances of estimated critical loads for total nitrogen and sulphur deposition for 1990 and 2013 (US EPA and ECCC, 2016).

and magnitude of exceedance is declining but that most recent data indicate that many areas in eastern North America still show substantial exceedances (Fig. 15).

Sulphur and nitrogen emissions also contribute to PM concentrations in the atmosphere. In fact, over the past decade, control of sulphur emissions has shifted from being primarily driven by reducing acidification to their role as precursors of atmospheric $PM_{2.5}$.

Sulphur and nitrogen compounds emitted to the atmosphere also cause damage to building materials, particularly through corrosion. Long-term monitoring data show that the rate of corrosion in Europe has decreased in parallel with the decline in emissions (Fig. 16).

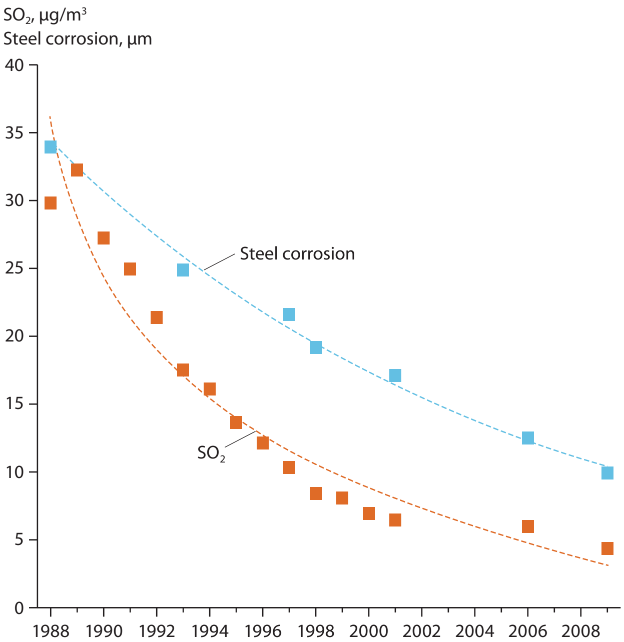


Figure 16. Trends in average corrosion rates and SO_2 concentration between 1998 and 2008 at 20 ICP monitoring sites in Europe (Tidblad et al., 2014).

Box 3. 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 desulphurisation, low-sulphur fuels and catalytic converters in cars were applied and the costs became lower as more countries used these cleaner technologies. Environmental measures were responsible for around a third of the decoupling between growth in production and consumption and the development of emissions. Energy policy and general technological progress also played a significant role in this decoupling: coal was substituted by gas and non-fossil energy and products, and production processes became more energy efficient. Future air pollution trends will continue to be influenced by both environmental measures and energy policy.

If economic growth and air pollution trends had not been decoupled, exceedance of critical loads for acidification in Europe would have been 30 times higher than at present. The total exceedance of critical loads for nitrogen would have been three times higher. Average $PM_{2.5}$ levels would have been similar to levels in current European 'hotspots', with three times more health impacts than today and the premature death of 600,000 more people. Health impacts from O_3 would have been 70% higher and O_3 damage to crops 30% higher. Overall, average life expectancy today is 12 months more than in the hypothetical unabated world.

Emission reductions were not only due to end-of-pipe control. The close connection to energy and energy policies has also been important in terms of emission reductions over recent decades. Historical energy data, plus 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 (Fig. 17). The study, covering the period 1960 to 2010, shows that 75% of the decline in SO_2 emissions in western Europe was from a combination of reduced energy intensity and improved fuel mix. The importance of control measures in Europe is further illustrated in Box 3. The importance of direct air pollution abatement measures has been greater in western Europe than in eastern Europe, where the transition towards a market economy in the 1990s played a dominant role in reducing emissions (Rafaj et al., 2014).

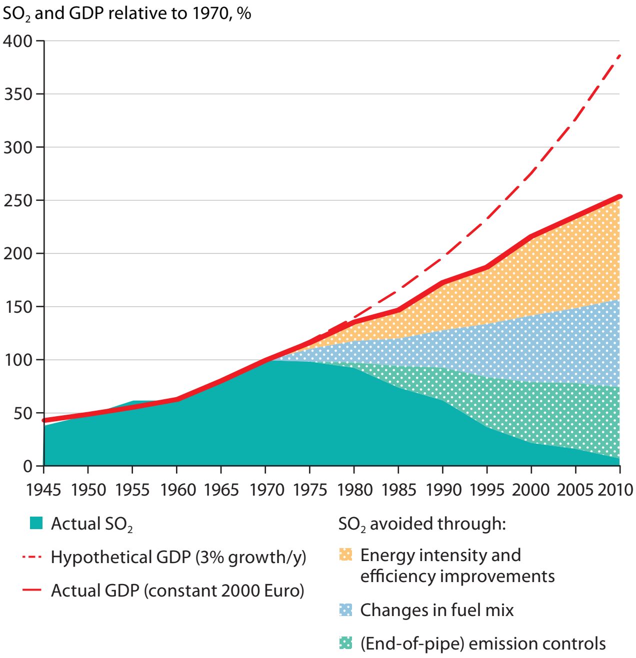


Figure 17. Determinants of reductions in sulphur dioxide (SO_2) emissions in western Europe (Rafaj et al., 2014).

4. Ozone trends and impacts on health and crop yields

There is evidence from models and observations that owing to emission reductions, peak concentrations of ground-level O_3 have begun to decline in several areas over the last decade. However, due to large interannual variations, a 10-year period is not long enough to detect trends at many locations. Average annual O_3 concentrations do not show a clear decline for several reasons. For example, in Asia, O_3 precursor emissions (including CH_4) have been increasing, and thus contributing to background O_3 in Europe and North America. Also, less O_3 is removed by NO_X emissions close to the source regions. Ozone is therefore still a threat to public health, crops and forests.

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

4.1 Health effects from short-term and long-term exposure

Short-term (few hours) exposure to O_3 is associated with mortality and respiratory morbidity (WHO Regional Office for Europe, 2013a). The EU Ambient Air Quality Directive target value for O_3 specifically addresses short-term health risks using a maximum daily 8-hour mean O_3 concentration of 120 μg/m^3 (or 60 ppb) not to be exceeded more than 25 times per year. The WHO advisory guideline value is 100 μg/m^3 (or 50 ppb) for a daily maximum 8-hour mean.

Both the United States and Canada recently set stricter ambient air quality standards for O_3. On 1 October 2015, the US EPA strengthened the NAAQS for ground-level O_3 from 75 to 70 ppb, based on extensive scientific evidence on the effects of O_3 on public health and welfare. The US EPA also strengthened the standard to improve protection for trees, plants and ecosystems based on new studies that add to evidence showing that exposure to O_3 reduces growth and has other harmful effects on plants and trees. Such effects have the potential to harm ecosystems and the benefits they provide. The EPA's final rule and risk assessment includes the latest scientific findings and conclusions about health and ecosystem impacts of O_3.

Canada has also established more stringent Ambient Air Quality Standards for O_3 of 63 ppb in 2015 and 62 ppb in 2020. These were established under the Canadian Environmental Protection Act 1999 and replace the previous Canada-wide Standard for O_3. The 2020 standard will be reviewed in 2016.

Monitoring O_3 at rural and urban sites throughout Europe shows that episodes of high ground-level O_3 concentration occur over most parts of the continent in summer, during warm and stagnant weather conditions (Fig. 18), and EU O_3 target

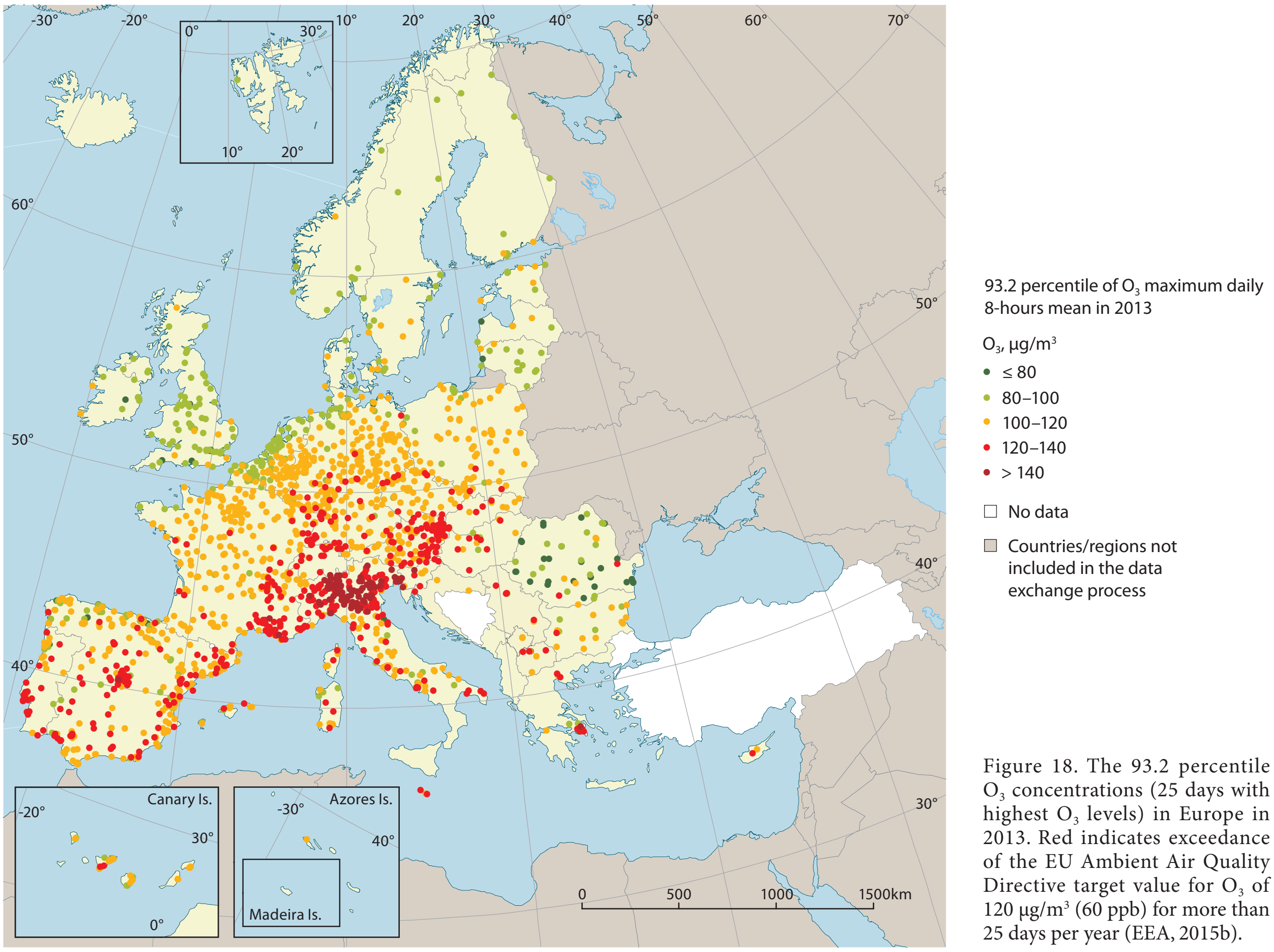


Figure 18. The 93.2 percentile O_3 concentrations (25 days with highest O_3 levels) in Europe in 2013. Red indicates exceedance of the EU Ambient Air Quality Directive target value for O_3 of 120 μg/m^3 (60 ppb) for more than 25 days per year (EEA, 2015b).

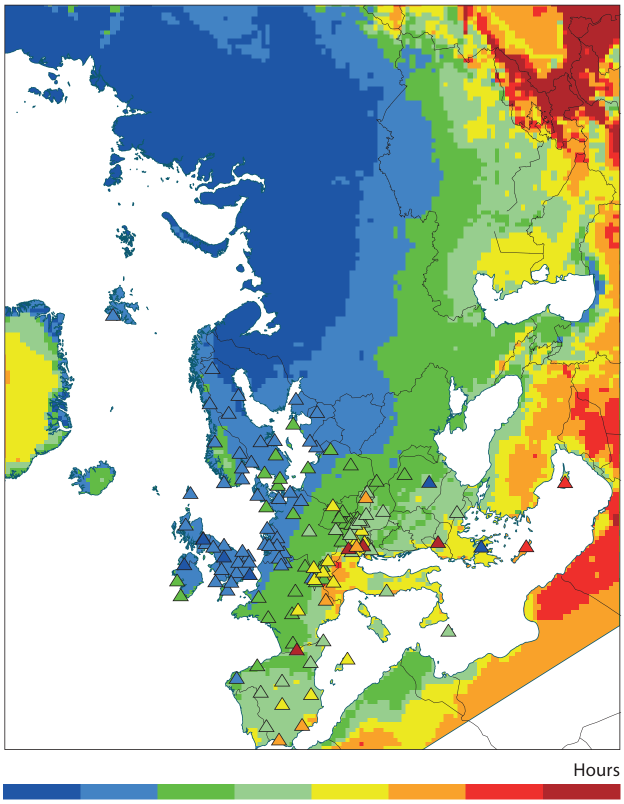


Figure 19. Calculated SOMO35 data (annual sum of the maximum of 8 hours running average O_3 over 35 ppbv) for 2013, together with observations (EMEP, 2015).

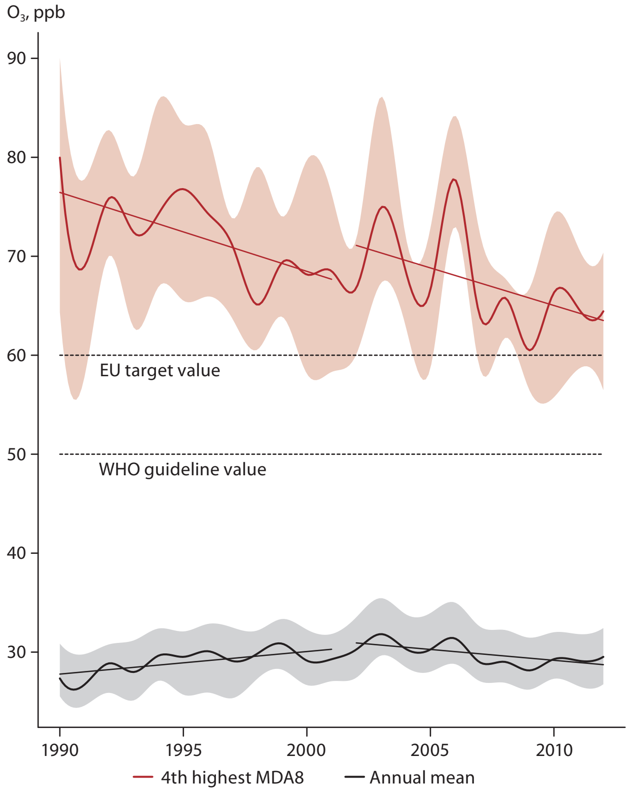


Figure 20. Evolution of ozone peak concentrations (4th highest daily maxima 8-hour mean ozone; MDA8) and annual mean concentrations at the 54 EMEP monitoring stations with satisfactory data coverage. Thick lines indicate the network median and shaded areas the 25th and 75th percentiles. Trend lines are indicative for the periods 1990–2002 and 2002–2012 (TFMM, 2016).

values are regularly exceeded in southern and central European countries. Measured and modelled SOMO35, an indicator for long-term risk of O_3 health impacts is also higher in southern Europe (Fig. 19). Similar episodes occur every summer over eastern North America.

Epidemiological studies provide accumulating evidence of mortality related to long-term O_3 exposure (WHO Regional Office for Europe, 2013a), although it is currently impossible to establish a lower threshold for absence of effects.

4.2 Peak ozone concentrations decline

Analysis at six coastal, rural and mountain-top sites in Europe showed that mean annual O_3 concentrations increased by 0.3–0.7 ppb/y through much of the 1980s and 1990s, but have 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 the periods 1990–1999 and 2000–2009, found generally increasing O_3 concentrations of 0.1 to 0.4 ppb/y up to the 95th O_3 percentile, and O_3 reductions of 0.5 to 1.5 ppb/y 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 (Fig. 20) shows that in the period 1990–2012, high O_3 concentrations declined by about 10% such that the number of days with exceedance of the WHO guideline of 50 ppb was reduced by about 20% since the start of the 1990s. During the period 2002–2012, the median SOMO35 across EMEP stations decreased by 30%. On the other hand, annual mean O_3 concentrations 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 O_3 concentrations in parts of Europe, but trends were only significant at 27% of stations. Thus, while summer peak O_3 values have reduced at several locations, probably due to emission reductions within Europe, studies indicated that a similar decline in mean O_3 levels was not observed.

In North America, emission control has also resulted in less exceedance of air quality standards. In Canada, although average O_3 concentrations were relatively constant between 1998 and 2012, peak O_3 concentrations decreased by 15% over the same period. Between 2003 and 2012, the percentage of Canadians living in communities where ambient ground-level O_3 exceed established air quality standards dropped from approximately 54% to 34%. In the United States, nationally, average O_3 levels declined in the 1980s, levelled off in the 1990s, and showed a notable decline after 2002. From 1990 to 2014 national average O_3 levels decreased by 23%.

The United States and Canada have committed to addressing transboundary O_3 under the Canada–United States Air Quality Agreement, by reducing emissions of NO_X and VOCs, the precursors to O_3. The commitments apply to a defined region in both countries known as the Pollutant Emission Management Area (PEMA), which includes central and southern Ontario, southern Quebec, 18 States and D.C., and where emission reductions are most critical for reducing transboundary O_3.

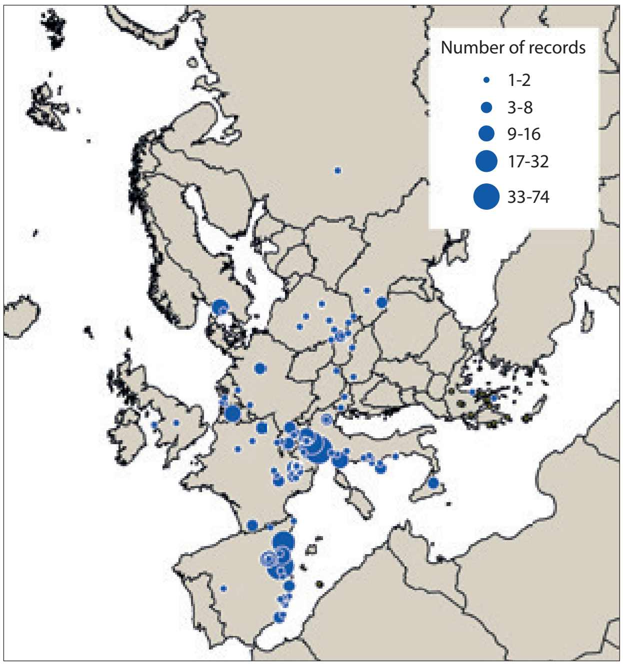


Figure 21. Visible ozone injury symptoms on wheat (*Triticum aestivum*) and locations of records of visible injury attributed to ozone on crops, (semi-) natural vegetation and shrub species for the period 1990 to 2006 (Mills et al., 2011).

The Canada–US collaboration to date has led to significant reductions. Between 2000 and 2012, Canada's total NO_X emissions in the PEMA region decreased by 45%, while those in the US PEMA region declined by 47%. For comparison, total NO_X emissions in the EU over this period decreased by 35% and VOC emissions by 40%.

4.3 Ozone damage to vegetation

Under environmental conditions conducive to high O_3 uptake, O_3 damage to vegetation occurs during the growing season at concentrations of 30 ppb or below. Effects include visible leaf-injury (Fig. 21), increased or premature die-back and reduced seed production and growth of sensitive species, including trees, (semi-)natural vegetation, and some important crop species, including wheat, soybean and rice (Mills and Harmens, 2011; Ainsworth et al., 2012).

Several methodologies are used to estimate O_3 damage to crops. One method widely used in Europe is the empirical indicator AOT40 (growing season O_3 above a threshold of 40 ppb). Globally (based on AOT40), O_3 is estimated to account for yield losses of 3–12% for the major staple crops (Van Dingenen et al., 2009). More recent O_3 flux-based estimates, taking into account the impact of environmental conditions on O_3 uptake, show wheat yield losses of EUR 4.6 billion in the EMEP region, equating to a yield loss of 13%, with the highest economic losses found in important wheat growing areas of western and central Europe, and about 40% in EECCA and SEE (South East Europe) countries alone (Fig. 22; Table 1).

4.4 Transcontinental fluxes influence ozone trends

The question now is why did peak O_3 start to reduce at a number of locations while average O_3 did not, despite a 40% reduction in European emissions of O_3 precursors between 1990 and 2013 (EMEP, 2015). There are several factors that must be considered. First, there are substantial natural variations in O_3 between years and even decades. Long, and high-quality observation time series are needed to detect changes, and such measurements are less abundant before 2000. Measurements starting around 2000 have not extended for long enough to detect trends. To detect O_3 changes, it is extremely important that observations are continued in the coming decade. Second, decreasing NO_X emissions can lead to increased O_3 concentrations (especially affecting the lower/middle O_3 concentration range) near the emission source, while the benefit in improving air quality will only be felt 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 O_3 inflow (Colette et al., 2011). Third, O_3 changes are variable across the world (Fig. 23), and inflow conditions of O_3 into Europe and North America may have changed (Wild et al., 2012; Doherty, 2015; Verstraeten et al., 2015). Strong and continued increases in O_3 have been observed in Asia and at the west coast of North America since 1990, while trends were mixed at other locations. Because tropospheric O_3 has a lifetime of about 20 days it can be transported across the northern hemisphere and O_3 produced from emissions in other regions can contribute to O_3 concentrations in Europe and North America. Natural large-scale O_3 variability, but also changing emissions in the northern hemisphere are likely to be contributing to the changing inflow conditions. Analysis performed by the Task Force on Hemispheric Transport of Air Pollution (HTAP)

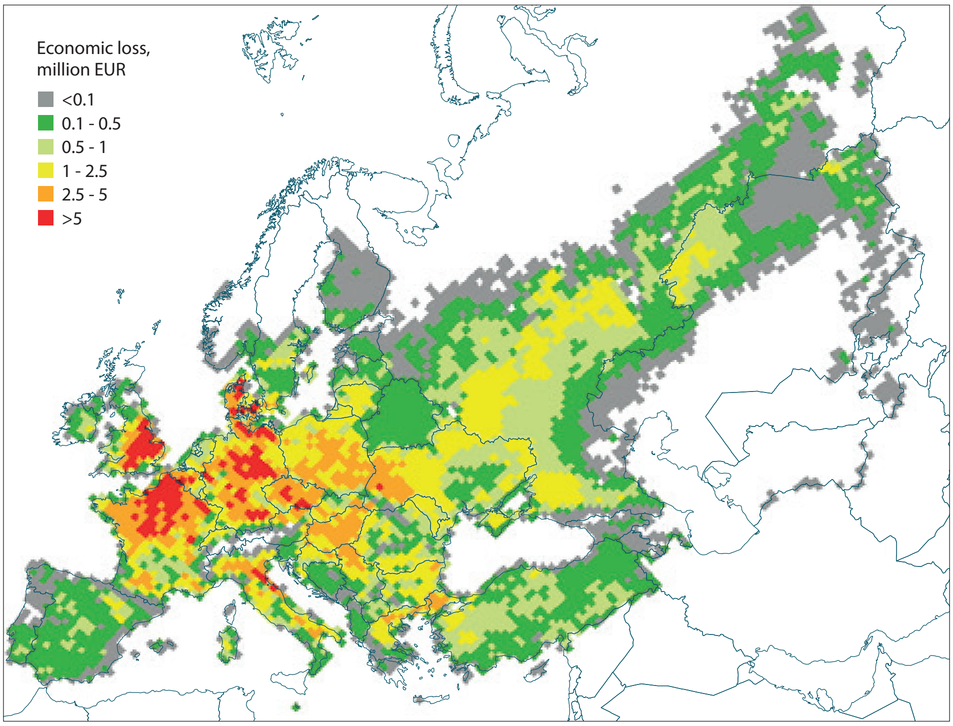


Figure 22. Wheat yield losses (million EUR per 50×50 km grid square), using rain-fed wheat production values for 2000 (www.fao.org/nr/gaez/en/), the calculated average ozone flux for crops (http://emep.int/mscw/index_mscw.html), and average wheat prices for the period 2007 to 2011.

Table 1. Summary of the wheat yield losses presented in Fig. 22 for different EMEP regions.

	EMEP region	EU28+[1]	SEE[2]	EECCA[3]
Total production loss (million t)	23.7	15.4	2.8	6.7
Economic loss (billion EUR)	4.6	3.0	0.5	1.3
Percentage yield loss	13.2	14.6	10.7	12.0

[1]Including Switzerland and Norway; [2]Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Macedonia, Montenegro, Romania, Serbia, Slovenia and Turkey; [3]Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

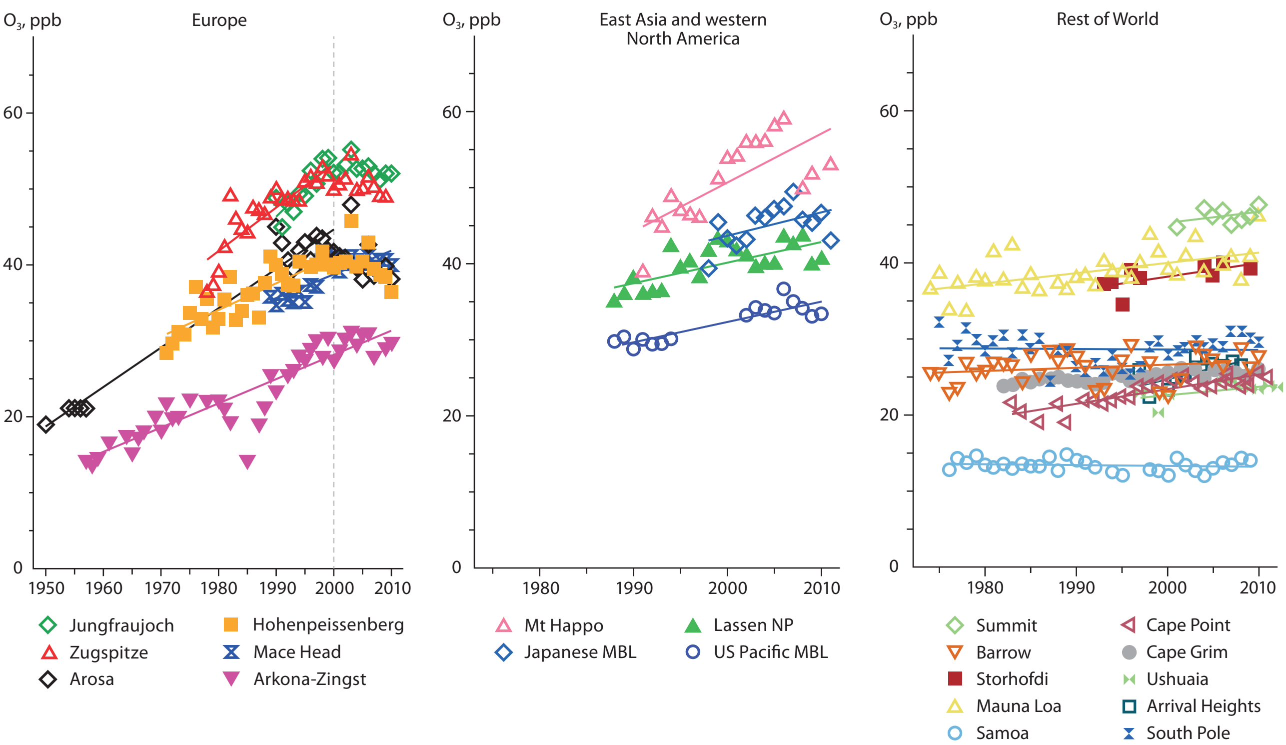


Figure 23. Surface ozone (O_3) time series at several rural sites around the world. Trend lines are fitted through the annual average O_3 values using the linear least-square regression method. Trend lines in Europe extend only through 2000 at which point the positive trend appears to end (Cooper et al. 2014).

indicates that declining O_3 contributions from air pollutant controls in North America have been compensated by increases from Asia and other parts of the world, and by increased CH_4 emissions (Fig. 24). In the coming decades, CH_4 emission controls will increasingly determine whether O_3 will further decline (see Ch. 8).

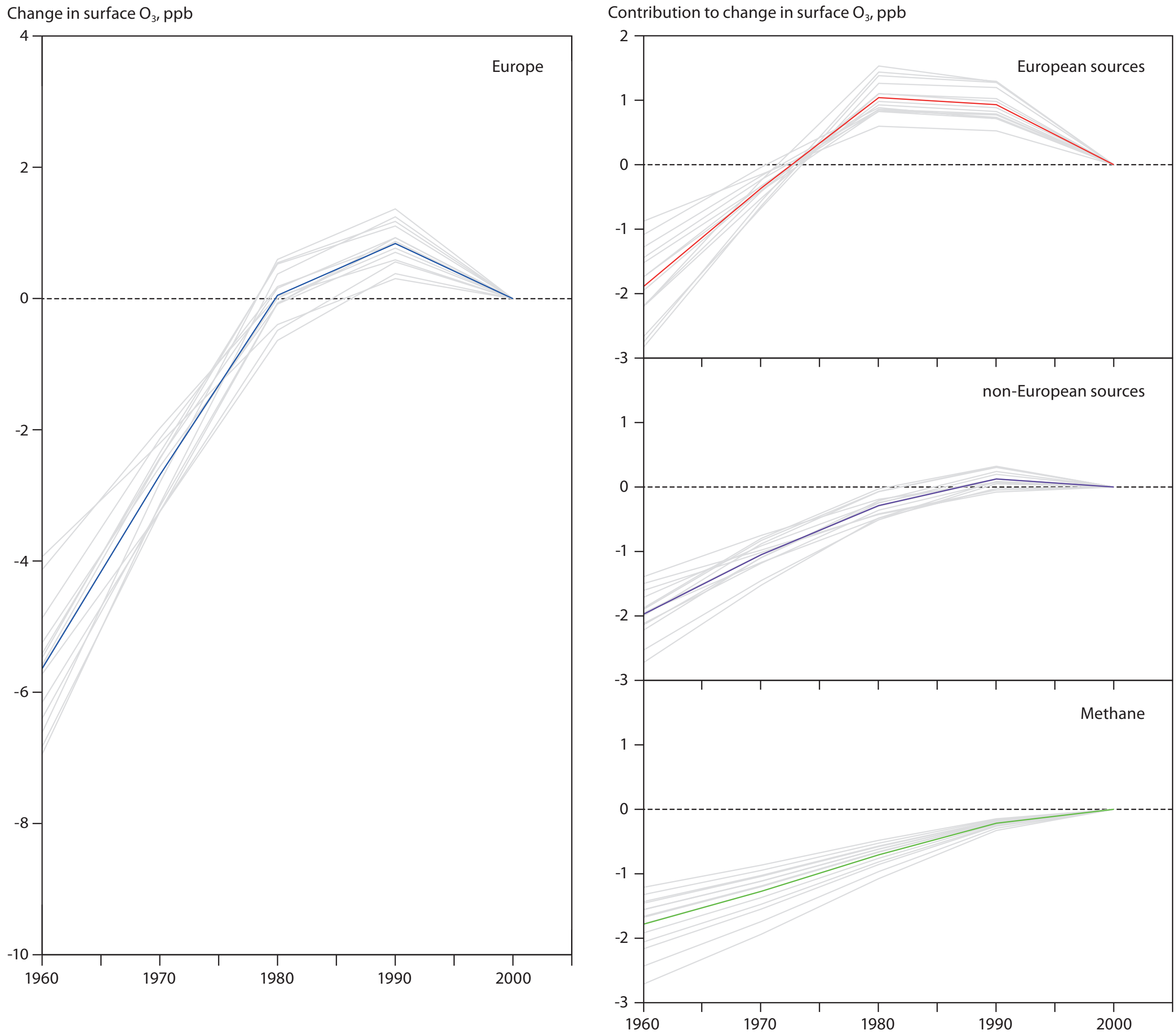


Figure 24. Calculated annual mean ozone (O_3) trends in Europe between 1960 and 2000 from an ensemble of models (Wild et al. 2012).

5. Persistent pollutants

Few improvements have been noted since the significant emission reductions of heavy metals and persistent organic pollutants (POPs) before 2005, and pollution levels are still a concern.

Heavy metals and POPs differ in several respects to the classic air pollutants in terms of sources, long-range atmospheric transport behaviour and regulatory context. Heavy metals and POPs are known for their toxicity and adverse effects on human health and the environment (carcinogenicity, mutagenicity, reproduction toxicity, and endocrine disruption). Heavy metals are elements that are naturally present in the environment. Their concentrations in ecosystems have been significantly enriched compared to the pre-industrial period owing to anthropogenic activities. POPs are either intentionally produced chemicals (e.g. pesticides and industrial chemicals) and/or unintentional by-products, often from combustion (e.g. polyaromatic hydrocarbons, PAHs; dioxins and furans, PCDD/Fs). Many POPs accumulate along food chains and within individuals: low environmental concentrations can lead to significant exposure over time. Many POPs also undergo reversible atmospheric deposition and so uncertainties remain as to whether contemporary atmospheric burdens reflect 'fresh' primary emissions amenable to additional control strategies or secondary emissions from previously-contaminated reservoirs.

5.1 Emissions

Anthropogenic emissions of heavy metals and some POPs were significantly reduced in EMEP countries over the past two decades. Emission inventories show declines of 60% (mercury; Hg) to 90% (lead; Pb) since 1990. POP emissions decreased by 40% (PAHs) to 85% (polychlorinated biphenyls, PCB; and hexachlorobenzene, HCB). Many POPs and POP-like substances not covered by CLRTAP are not monitored regularly but the overall emissions of persistent chemicals are likely to be increasing or remain unchanged. For some sectors the emission reductions have been significant; for example, Pb emissions from road transport ended following the introduction of catalytic converters in petrol-driven cars. These days, deposition of the three metals addressed under CLRTAP (Pb, Cd, Hg) is mainly from industrial combustion, non-industrial combustion, metal production and energy generation (Fig. 25). For the carcinogenic benzo[*a*]pyrene (BaP; an indicator of several POPs from combustion) major emissions originate from residential heating and industry-related sources.

There has been a similar decline in emissions of 187 toxic pollutants (including Hg, Pb, Cd and some POPs) in North America. In the United States, emissions of toxic air pollutants (187 including Hg, Pb, Cd and some persistent pollutants) declined by 60% between 1990 and 2011.

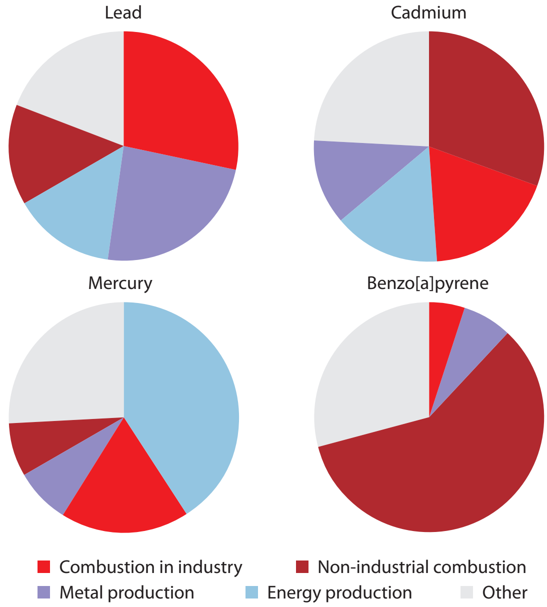


Figure 25. Relative contribution of the key source categories to atmospheric levels of lead, cadmium, mercury and benzo[*a*]pyrene in EMEP countries in 2010 (data from MSC-E).

5.2 Atmospheric trends

Emission control has led to a decline in atmospheric concentrations within the EMEP area (Tørseth et al., 2012). All EMEP sites with measurements since 1990 show significant reductions in concentrations of Pb (up to 90%) and Cd (up to 70%). For Hg the observed levels decreased significantly to the end of the 1990s and have since levelled off. Modelled heavy metal levels show a similar trend with levels declining from 78% (Pb) to about 23% (Hg) (Fig. 26). The decline in POP levels (as far as monitored under CLRTAP) ranged from

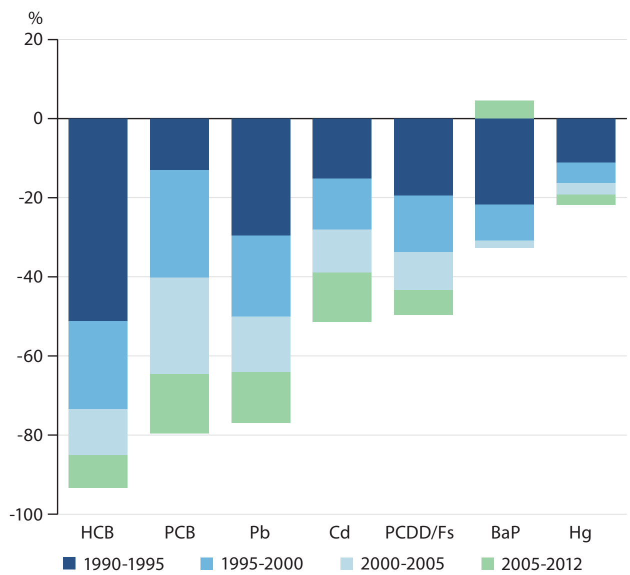


Figure 26. Relative reduction in heavy metal and persistent organic pollutant levels simulated by models for the period 1990–2012 in the EMEP region (data from MSC-E).

Figure 27. Lumped long-term trends in concentration for selected POPs in air from some EMEP sites. Data represent up to seven sites and up to two decades of monitoring (WEOG, 2015).

about 90% (HCB) to about 30% (BaP). The rates of decline were not uniform and differed among the pollutants. Models results show Pb and HCB levels decreased rapidly in the early 1990s and that since 2000 the decline has slowed. The decline in Hg and Cd levels has been relatively consistent over the entire period. Levels of BaP and PCDD/Fs are characterised by a fast reduction in the period 1990–2000, replaced by some growth at present. The long-term changes simulated by models are in general agreement with observations from the EMEP monitoring network. Similar rates of reduction for heavy metals are demonstrated by changes in heavy metal concentrations in mosses (Harmens et al., 2015).

Long-term monitoring efforts under CLRTAP have increased understanding of the temporal and spatial distribution of heavy metals and many POPs. However, long-term trends often vary across sites and pollutants, as illustrated for POPs in Fig. 27. Some organochlorine pesticides that have now been banned for some time show a sharp decline (e.g. gamma-hexachlorocyclohexane, γ-HCH), while for other POPs no trend has been seen (e.g. HCB). Even within groups of similar POPs such as the PCBs, differences in trends are evident (e.g. for the congeners PCB52 and PCB153).

Reduction in pollution levels varies strongly among EMEP countries. While EU28 countries show a much stronger reduction than the EMEP-average, reduction is relatively modest in EECCA countries. Ambient air pollution has declined in a similar manner in North America. Control measures have been particularly successful for Pb, with ambient air concentrations falling by 97% between 1990 and 2014.

5.3 Transboundary transport and secondary sources

Levels of heavy metals and POPs in air are influenced by anthropogenic emissions, secondary sources in the EMEP region, and intercontinental transport. For Pb and Cd the decline is less than the reduction in anthropogenic emissions owing to the effect of secondary emissions for which long-term changes are relatively small. Mercury levels are strongly affected by emission sources outside the EMEP region. Declines in HCB, PCB and PCDD/Fs levels largely depend on long-term changes in secondary emissions. The decline in these POPs is mainly linked to strong regulation within UN ECE countries on major stationary sources. Without these regulations the trends could reverse.

Model estimates indicate that intercontinental transport of Hg as well as of PCDD/Fs, HCB, and PCBs can make a substantial contribution to pollution levels in EMEP countries (Fig. 28). In particular, Hg deposition on average comprises almost equal contributions of contemporary anthropogenic emissions and emissions from secondary sources (Fig. 29). Half the anthropogenic component is contributed by emissions within the UN ECE region with the rest by transport from sources in other regions. The largest external contributors include East Asia (11% of total deposition), Africa (4%), Southeast Asia (2%)

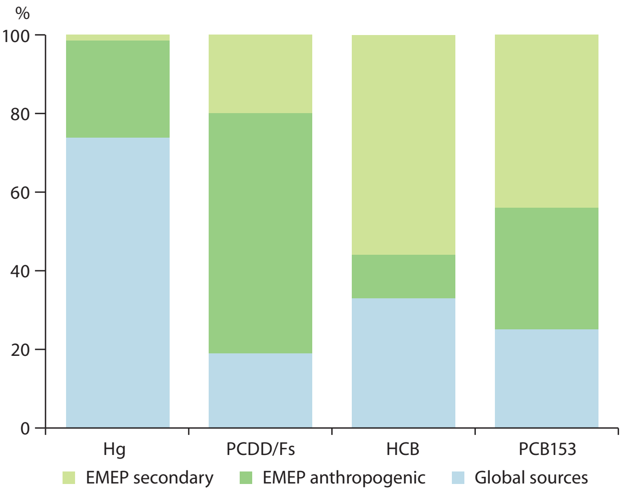


Figure 28. Relative contribution of different source types to air pollution in EMEP countries Global sources include anthropogenic and secondary emissions (data from MSC-E).

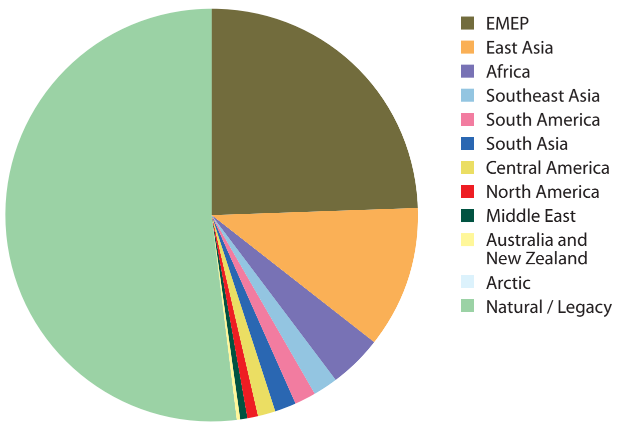


Figure 29. Source attribution of average mercury deposition in EMEP countries (data from MSC-E).

and South America (2%). A similar or even larger contribution of secondary sources (re-emission) is typical for HCB and PCBs, which cycle between the atmosphere and other environmental compartments over periods of decades.

5.4 Impacts

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 (such as via uptake in food chains which may play a significant role in remote areas such as the Arctic). 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.

The decline in pollution levels between 1990 and 2010 has resulted in reduced impact for both human health and biota. However, human health and ecosystems continue to be at risk in many EMEP countries despite major reductions in heavy metals and POPs. Critical loads of Pb and Hg (Fig. 30) are still exceeded in several countries. High Cd deposition still occurs in a number of 'hotspots' close to industrial regions.

Although the number of people exposed to BaP concentrations above the EU target value of 1 ng/m^3 (Directive 2004/107/EC) is now around six-fold lower than in 1990, the number of people affected is still significant at around 16 million. The number of people living in such areas in selected UNECE countries is shown in Fig. 31.

The global and biogeochemical cycling of Hg and POPs includes not only atmospheric transport and transformations but also interactions with the earth's surface, with deposition processes as well as re-emission important factors in the fate of these contaminants. Marine transport, biological transport and international transport in goods and e-waste (electric and electronic devices) form part of the global cycle. Multi-

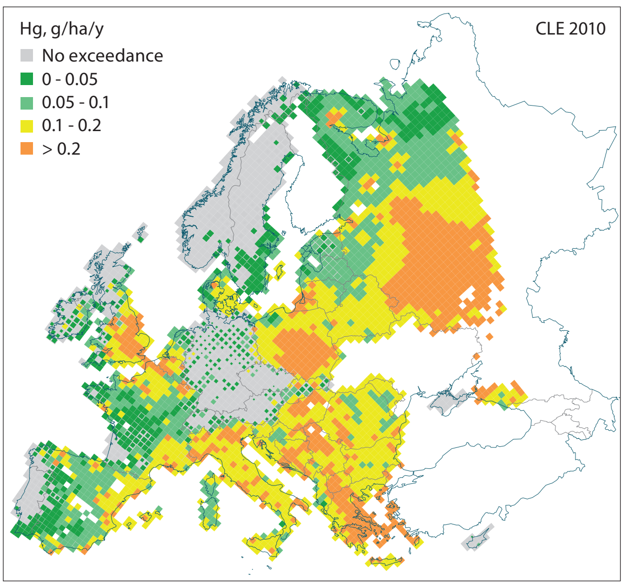


Figure 30. Computed critical load exceedance of mercury in 2010 assuming implementation of current legislation (based on Hettelingh et al., 2015).

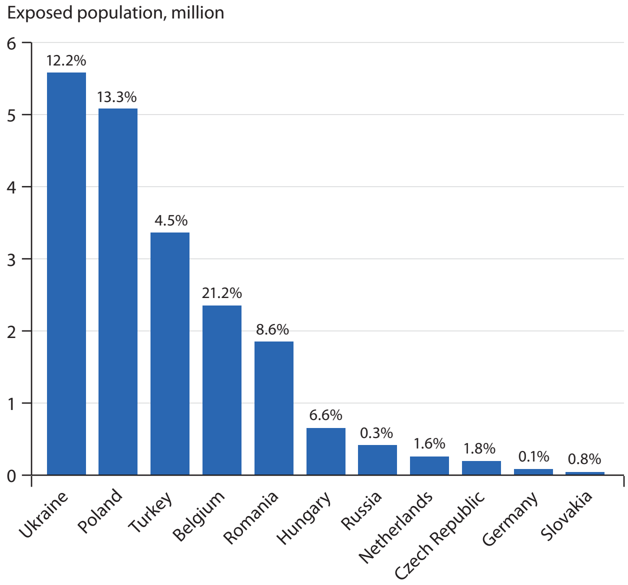


Figure 31. Population exposed to BaP concentrations in ambient air above the EU target value of 1 ng/m^3 in selected EMEP countries in 2012. Numbers above bars represent the exposed population as a percentage of the total population of the country. The model calculations are based on officially reported emission data (data from MSC-E).

compartment aspects are especially important when modelling inter-continental transport where interactions between the atmosphere, land and oceans are of importance. This global aspect was the foundation for the Stockholm Convention and the Minamata Convention.

5.5 Remaining issues

Health effects are still being seen in the UNECE region due to the long-range transport of heavy metals and POPs. Since a significant proportion of the deposition in many regions has a hemispheric or global origin, effective policies would need to take these geographic scales into account. Better emission data, knowledge about remaining abatement options, improved monitoring and scientific understanding, and modelling of the fate of pollutants through air, water, soil and biota would be useful for effective future agreements.

6. Air pollution abatement benefits the economy

With current policies, the number of life-years lost due to PM in the EU is projected to decrease by 40% between 2005 and 2030. Technically a further 20% reduction is possible (Amann, 2014). The costs of such an effort is estimated at EUR 50 billion (or 0.3% of GDP). Almost 90% of the potential health benefits are obtained at 6% of the costs. Such a 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) (EC, 2013; EC4MACS, 2013).

The costs of air pollution abatement in 2030 can be reduced substantially (almost 60%) by implementing a successful climate and energy policy, for example, by energy saving and replacing fossil fuels by renewable energy (IIASA, 2014). Moreover air pollution abatement costs are estimated conservatively: technological changes and economies of scale (e.g. fast implementation of electric vehicles) have not been taken into account. The average costs of an optimal air pollution strategy are 0.01–0.02% of GDP, although these percentages are higher in countries with a low GDP. Financial and technological assistance could help 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.

6.1 Health damage has significant costs

Morbidity and premature mortality due to air pollution are associated with significant economic costs. These include, but are not limited to, costs to society from premature deaths, healthcare costs for illness, and loss in productivity associated with sickness-related absence from work (Holland, 2014). Therefore, in addition to health benefits, air pollution abatement can achieve significant cost savings. According to a joint study by the WHO and OECD, the combined cost of premature deaths and diseases caused by air pollution in the 53 countries of the WHO European Region was about USD 1.6 trillion in 2010 (WHO Regional Office for Europe and OECD, 2015). This represents the amount societies are willing to pay to avoid these deaths and diseases by intervention (WHO Regional Office for Europe and OECD, 2015). In the EU, health-related costs associated with air pollution were EUR 330–940 billion in 2010, and are expected to decline under a business-as-usual scenario (baseline projection) to EUR 210–730 billion in 2030 (2005 prices) (EC, 2013). The corresponding economic benefits of the proposed national emission ceilings of the EU air policy package can be monetised, corresponding to about EUR 40–140 billion, with the costs of pollution abatement to implement the package estimated at EUR 3.4 billion (per year in 2030). The monetised benefits will therefore be about 12 to 40 times greater than the costs incurred (EC, 2013).

The annual economic cost of premature deaths, heart attacks, hospital admissions, emergency department visits, and missed school work exceeds USD 1 trillion per year in the United States, while the annual cost of air pollution related impacts on human health in Canada is more than CAD 8 billion.

By meeting current commitments through ratification and implementation of CLRTAP protocols, many Parties would see more cost-effective reductions in health and environmental impacts than could be achieved by unilateral action alone.

Box 4. Cost-benefit analyses in North America

The impacts of air pollution on the Canadian economy include direct economic impacts as well as indirect economic impacts stemming from the human health and environmental effects of air pollution. For Canadians, a 2008 analysis by the Canadian Medical Association estimated that as many as 21,000 premature deaths per year were associated with air pollution, along with hundreds of thousands of asthma and respiratory symptom days, and millions of minor illnesses and restricted-activity days (Canadian Medical Association, 2008). The cost of human health damage from air pollution was estimated at over CAD 8 billion per year, through premature death, worker absenteeism, higher health care costs and other factors.

Although the costs of reducing air pollution can be high, most recent cost-benefit studies in Canada such as the Cost-Benefit Analysis: Replacing Ontario's Coal-Fired Electricity Generation (Ontario Ministry of Energy, 2005) demonstrate that, at current pollution levels, the potential benefits to Canadians of air pollution reduction are much greater than the costs of implementing the reductions. Efforts to reduce air pollution may also lead to innovative new industries and economic spin-offs related to green technology. Several tools are being used, including regulations and partnerships, to encourage activities that support both the environment and the economy. For instance, new technologies, cleaner fuels, science and research, electricity generation and conservation, alternative transportation, and new forms of infrastructure can stimulate economic growth in a way that also helps the environment.

In the United States, effective implementation of clean air laws and regulations, as well as the use of efficient control technologies, has resulted in significant improvements in air quality. Despite good progress in air quality improvements, 57.3 million people were still exposed to ambient air quality concentrations above those of the US NAAQS in 2014. The US EPA estimated that exposure to recent air pollution contributed to 1 in every 20 deaths in the United States and showed that reducing exposure to PM and O_3 nationwide by 33% would avoid about 43,000 premature deaths, tens of thousands of non-fatal heart attacks and respiratory and cardiovascular hospitalisations, and hundreds of thousands of acute respiratory symptoms. The economic costs of premature deaths, heart attacks, hospital admissions, emergency department visits, and missed school work exceeds USD 1 trillion per year (Fann et al., 2012).

The more Parties ratify the protocols, the larger the scale of the market for cleaner technologies, and the lower their costs. Implementation would also ensure 'a level playing field' for industry, and prevent Parties competing with each other at the expense of human and environmental health. This may prove important in free trade negotiations.

The GEM-E3 model of the Joint Research Centre of the European Commission (JRC) shows that the macro-economic impacts of additional air pollution abatement measures are close to zero (EC, 2013). Comparable results were found for additional climate and energy measures (Bollen and Brink, 2012; Bollen et al., 2009). One of the reasons for this is that such measures would increase costs in some sectors (e.g. energy or agriculture) while simultaneously creating jobs in others (e.g. construction or the metals industry). Air pollution abatement measures could increase production costs in exporting sectors and lead to a loss of competitiveness and jobs. These effects would be considerably less with an increase in the geographical coverage of the international agreement to reduce air pollution. Investment in abatement measures could decrease investment in production capacity, but could also lead to less waste of energy or materials and more efficient production processes. Cleaner air would mean a healthier work force and less sickness-related absence from work. This could lead to lower labour costs and increase the competiveness of the economy (Holland, 2014; EEA, 2015b). Cost-benefit analyses in North America show comparable results (see Box 4).

Air pollution policy has winners and losers. However cost-benefit analyses of air pollution abatement strategies consistently show that societal benefits are substantially higher than the costs for some sectors.

7. Transboundary and multi-sectoral approaches

Atmospheric emissions of most pollutants have decreased significantly in the UNECE region over the past two decades. Ambient air concentrations have also decreased but not to the same extent, and it can be disappointing for stakeholders that efforts to reduce emissions are sometimes not immediately matched in population or ecosystem exposure. The key underlying factor is that air pollution and deposition reflect multiple factors. For example, atmospheric transport processes and chemistry influence the impact of pollutant sources over large domains and this is why the spatial scale for air pollution control often needs to extend well beyond the most exposed and affected areas. To achieve major improvements and meet long-term objectives, an effective transboundary approach would even need to extend beyond the current UNECE region to tackle several of the most important air pollution issues.

7.1 Future projections

For a 'business as usual' (i.e. baseline) emissions scenario, models project that the impacts of air pollution will continue to decrease. Beyond 2020, and without further measures, reductions in health impacts from air pollution are expected to progress at a considerably slower rate. Under the baseline scenario, average in loss of life expectancy in the EU attributable to $PM_{2.5}$ exposure is projected to decline from 8.5 months in 2005 to 5.3 months in 2025. However, by implementing the maximum technically feasible reduction measures in the EU, average loss in statistical life expectancy could be further decreased by 2030 to about 3.6 months.

According to the European Environment Agency (EEA) in 2020 around 144,000 cases of premature death could be avoided within the EU by achieving the WHO Air Quality Guideline level of 10 µg/m³ (EEA, 2015b). In North America, projections of $PM_{2.5}$ emissions and emissions of $PM_{2.5}$ precursors based on established policy in Canada and the United States suggest a continued decline in emissions and model results indicate a further decline in ambient $PM_{2.5}$ concentrations up to 2030.

7.2 Ammonia is becoming an important source of PM exposure

Use of fossil fuels and biomass for electricity generation, heating and transport, and industrial sectors, as well as nitrogen emissions 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, nmVOCs and PM could benefit from international climate and energy policies aiming to reduce the use of fossil fuels. Ammonia emissions from agriculture however would not benefit from such policies and thus require specific attention from air quality managers. Some CH_4 mitigation measures, such as biogas production for manure or changes in cattle feed, could even increase NH_3 emissions if not accompanied by additional NH_3 regulation (Amon et al., 2006; Reis et al., 2015; TFRN, 2015). The transboundary component of air pollution remains important: secondary inorganic particles (ammonium sulphate and ammonium nitrate) form an important component of the transboundary fluxes of PM and make a significant contribution to population exposure in several European cities (see Fig. 32; left and middle panels). Use of biomass and coal for residential heating forms an important source in others (see Fig. 32, right panel).

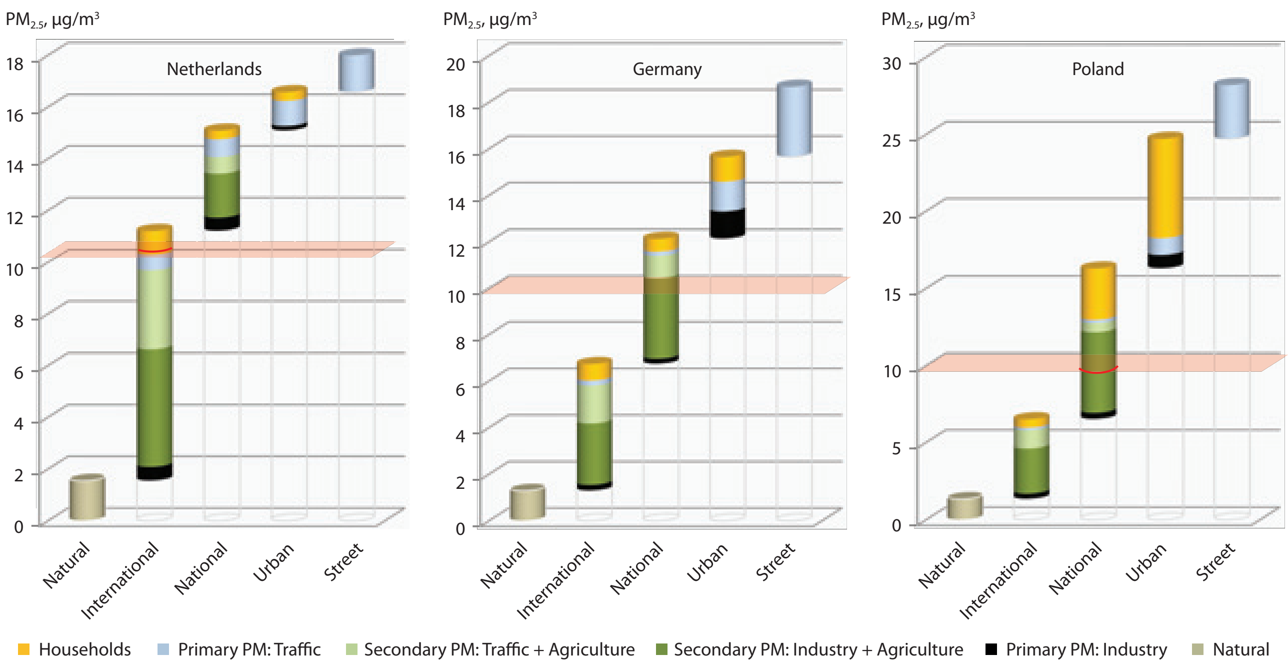


Figure 32. Sectoral contributions to $PM_{2.5}$ exposure in cities in the Netherlands, Germany and Poland in 2009 (Kiesewetter and Amann, 2014). Secondary PM Traffic+Agriculture is ammonium nitrate, NH_4NO_3; Secondary PM Industry+Agriculture is ammonium sulphate, $(NH_4)_2SO_4$.

Effective reduction of $PM_{2.5}$ levels to meet the WHO annual guideline value of 10 μg/m^3 cannot be achieved by isolated local measures, but needs to involve multiple economic sectors, and must be internationally coordinated. Remaining 'hotspots', especially in large cities or cities where local meteorology and site characteristics contribute to high PM levels can be largely managed by additional local control measures, but relying on local policies alone to address PM exposure in cities may be inefficient if the WHO air quality guideline values are targeted.

Source apportionment studies demonstrated the large influence of long-range transboundary transport on PM patterns in Europe. Figure 32 clearly illustrates the influence of transboundary and national contributions to $PM_{2.5}$ concentrations in Dutch and German cities, and the limited improvement that can be expected from local control policies alone. Although international/local ratios differ across Europe (see Polish cities) depending on city location, industrial profile and technologies already implemented, a significant proportion of the measures to reduce PM exposure in cities must in most cases be the result of further international or national abatement strategies.

7.3 Transboundary air pollution policy remains important

The CLRTAP protocols provide a prime example of effective internationally coordinated strategies that involve emissions of multiple substances emitted from a wide range of economic sectors. This also points the way towards achieving the WHO guideline values across Europe in the most cost-effective way.

However, although historically controls have mainly focussed on emissions from the power sector, industry and transport, for further air quality improvements the focus must expand to include small stationary combustion sources, especially in the residential and commercial sector, and agriculture.

Although additional emission controls bring additional costs, the tools developed under CLRTAP can identify cost-effective portfolios of measures in different sectors that achieve the envisaged health improvements at least cost. Such analyses take 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 those sectors for which this is not the case additional measures, although cost-effective from a social planner's perspective, might place disproportionate burdens on certain groups of society or particular economic sectors.

7.4 Measures to reduce ammonia are beneficial for health and nature

As previously mentioned, in Europe NH_3 emissions from agriculture emerge as a key focus for further measures. All analyses indicate a strong need for substantial reductions in NH_3 emissions in Europe, both for approaching the WHO guideline values for $PM_{2.5}$ because the formation of secondary inorganic aerosols is strongly influenced by the availability of NH_3 in the atmosphere (see Box 5) and for preserving biodiversity of ecosystems, which is threatened by excess nitrogen deposition.

Box 5. Secondary particles

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

A WHO review of the health effects of air pollution (WHO Regional Office for Europe, 2013a) has established $PM_{2.5}$ mass concentrations (including secondary inorganic aerosols) as the most health-relevant particle metric for mortality, and the WHO guideline value for fine particulate matter is defined in terms of $PM_{2.5}$ mass concentration. As the formation of secondary inorganic aerosols is steered by the abundance of NH_3 in large areas of Europe (EEA, 2015b), controls on NH_3 emissions emerge as the logical requirement for an effective reduction in health effects. However, as the WHO pointed out, it cannot be ruled out that the potency of various health effects differs for different components of PM.

This uncertainty could have 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 CLRTAP protocols, a multi-effect perspective that addresses health impacts in conjunction with, for example, biodiversity concerns, offers a robust risk management approach that hedges against the uncertainty of the health impacts of secondary inorganic aerosols. But even if these aerosols were not linked to negative health effects, NH_3 reductions would still be warranted for the protection of biodiversity.

Huge PM spring episodes that still occur in western Europe are mainly influenced by agricultural practices (manure and fertiliser spreading) that generate large NH_3 emissions under favourable meteorological conditions. Modelling results show that a significant decrease in PM peaks can only be achieved through concerted action in several countries (Bessagnet, 2014; EEA, 2015b).

7.5 Wood burning

The influence of residential heating and wood burning to transboundary and national PM exposure is also high but more difficult to assess because of uncertainties in emission inventories of semi-volatile organic compounds that condense to PM away from the source. Differences across countries in wood burning practices and technologies makes concerted management more challenging than controlling large combustion plants or road transport. Several countries have experience with tackling wood burning (see the North American example in Box 6). Nevertheless, coordinated action could lead to significant emission reductions.

Box 6. Black carbon as a component of $PM_{2.5}$

Black carbon is a component of $PM_{2.5}$ resulting from the incomplete combustion of fossil fuels, biofuels and biomass. The transportation sector is by far the most important source of black carbon emissions in many countries. Residential wood burning is the second largest source. The remainder is contributed by oil and gas industries and other industrial sources.

In the EU, Canada and the United States, domestic action has been taken to address air pollution through a range of measures and regulations that also reduce black carbon, such as motor vehicle inspections and diesel retrofit programs, regulations on the sale of wood burning appliances and wood-stove change-out programs, and measures to reduce flaring from oil and gas operations.

In the United States, black carbon emissions account for 11% of fine particle emissions. In 2011, transport and biomass burning were the largest sources of black carbon in the United States (US EPA, 2011).

The US EPA also encourages States to assess climate change and air pollution together and account for the potential effects of climate change in their multi-pollutant planning efforts.

8. Air pollution at a wider scale

Air pollution related to O_3 and some of its precursors, or to Hg and POPs (such as PCDD/Fs, PCBs and HCB), is significantly influenced by sources around the world. The first steps towards sharing knowledge at a wider geographical scale and defining potential cost-effective measures have been taken both by the CLRTAP Task Force on Hemispheric Transport of Air Pollution (HTAP) and the Arctic Council and UNEP's Climate and Clean Air Coalition (CCAC). Moreover knowledge and experience from CLRTAP is being shared with global Conventions on Hg and POPs.

8.1 Hemispheric scale of ozone pollution

Tackling damage from long-term O_3 exposure to public health, crops and forest growth in Europe effectively, may require a northern hemisphere abatement strategy. Although peak concentrations of O_3 have declined in parts of Europe, background concentrations in some major regions of the northern hemisphere, such as Asia and the west coast of North America, show a rising trend. While peak O_3 concentrations are largely determined by local emissions of NO_X and VOCs, on hemispheric to global scales O_3 concentrations are also determined by emissions of the long-lived greenhouse gas CH_4 and CO, as well as by natural variability of biogenic emissions and transport of stratospheric O_3 into the troposphere. Together, NO_X, VOCs, CO and CH_4 interact to form O_3, changing the oxidation capacity of the troposphere (governed by the reactive OH radical) and forming long-lived reservoir species such as peroxyacetyl nitrate (PAN).

8.2 Global ozone precursor emission changes between 1990 and 2010

European emissions of O_3 precursor gases NO_X, VOC, and CO declined by more than 40% between 1990 and 2013 (TFMM, 2016), with similar reductions achieved in North America. In contrast, emissions have increased by 20–30% in the rest of the world, and by as much as 50% in emerging economies such as China and India. Global anthropogenic emissions of CH_4 were stable through the 1990s, but increased in the 2000s (Fig. 33).

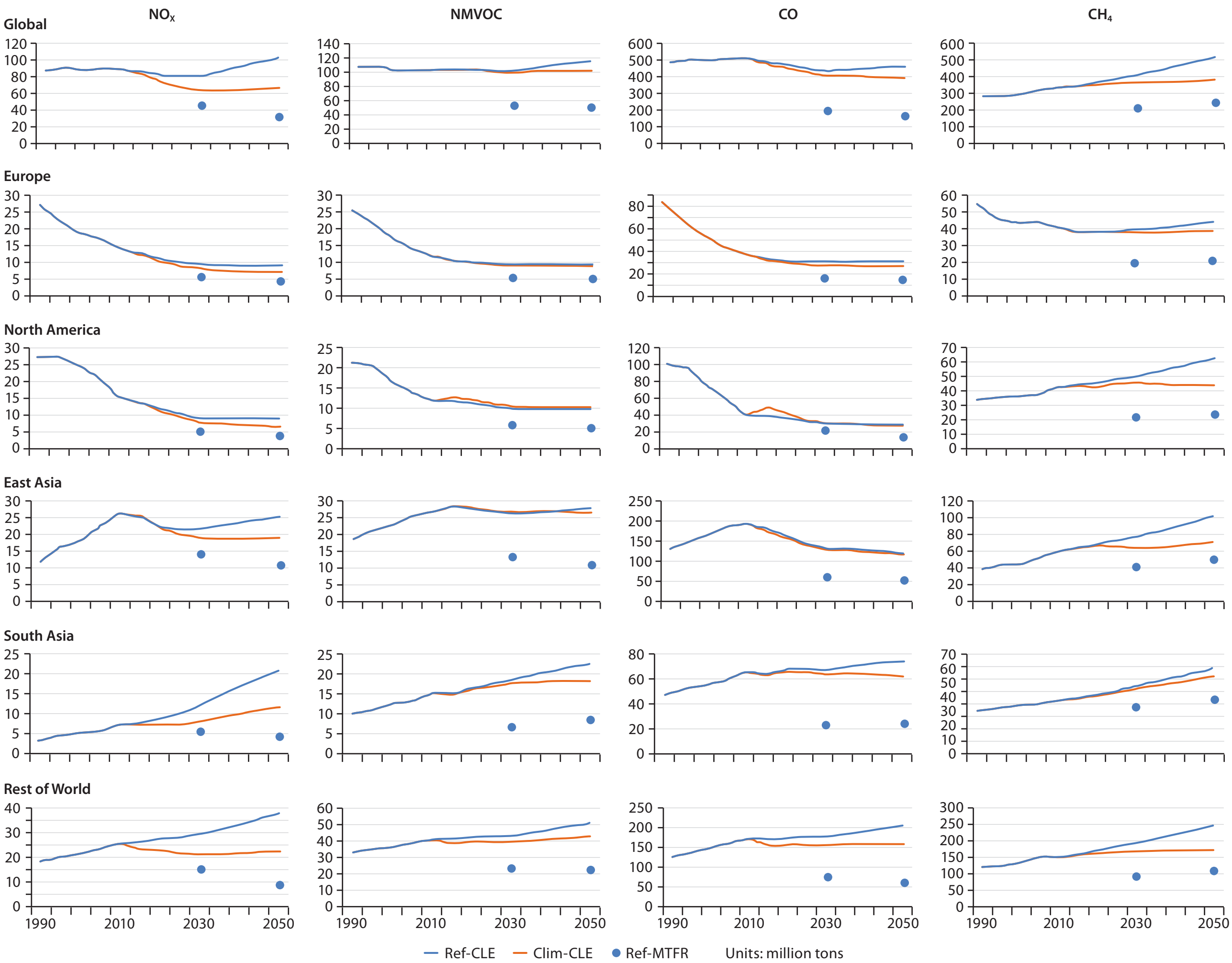


Figure 33. Trends in anthropogenic emissions (million tons) of nitrogen oxides (NO_X, as NO_2), non-methane volatile organic compounds (nmVOC), carbon monoxide (CO) and methane (CH_4) for the world and five major regions, and the Ref-CLE (current legislation scenario for air pollution), Clim-CLE (current legislation scenario for air pollution including climate mitigation measures) and Ref-MTFR (maximum technically feasible reduction scenario for air pollution) scenarios. The first scenario year is 2015 (Amann et al., 2013).

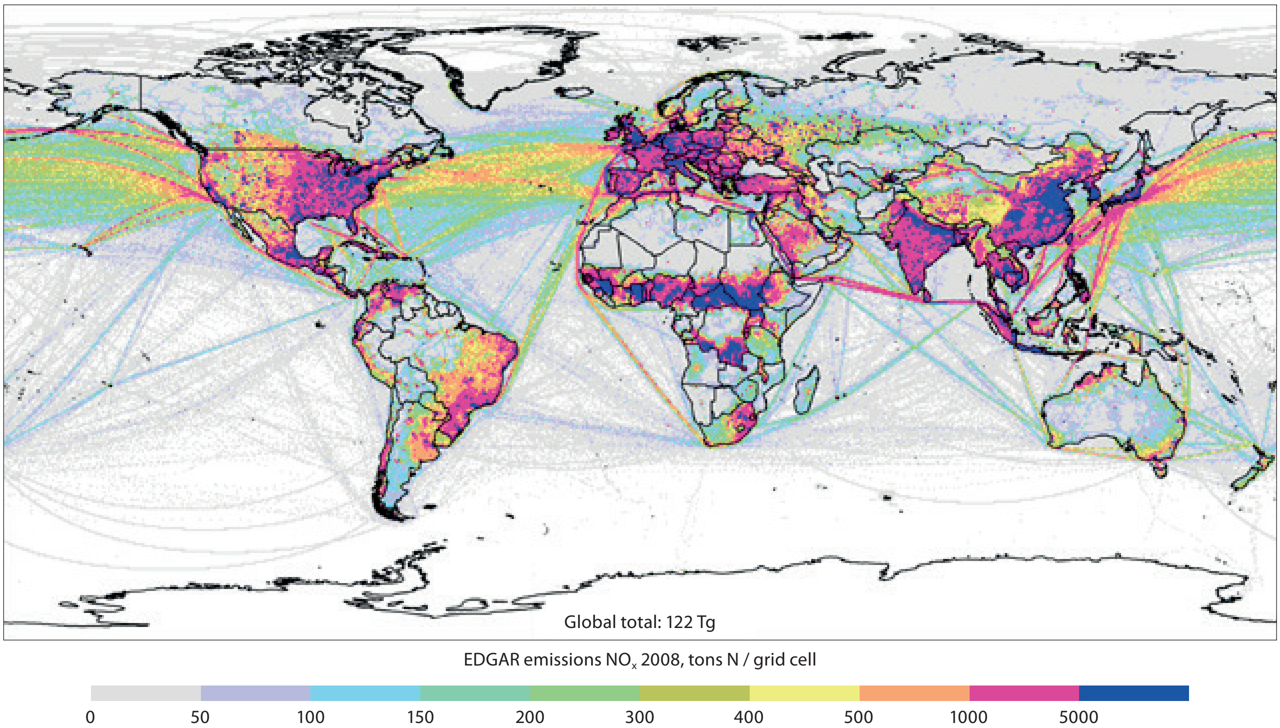


Figure 34. EDGAR global emission map for nitrogen oxides (NO_X) for 2008, showing the global distribution of emissions (http://edgar.jrc.ec.europa.eu/gallery.php?release=v42&substance=NOx &sector=TOTALS).

Its 10-year lifetime and uniform global distribution, mean the global abundance of CH_4 can be determined accurately. Methane observations from the global NOAA network show strong increases until 1998, followed by a decade of near-stagnation, and then resumed growth since 2008. Strong interannual variability in natural sources and sinks, but a long-term underlying trend that is driven by anthropogenic emissions are consistent with these observations.

North America and Europe continue to receive transport of particles and gases from other continents (Fig. 34). The transport of particles and gases from Asia, Europe and Africa across the Pacific Ocean increases background concentrations of pollutants over North America. Conversely, North America contributes to global pollution levels through the prevailing atmospheric circulation that carries particles and gases away from the continent and over the Atlantic Ocean. Although some fraction of the pollution exported by North America across the Atlantic Ocean can circle the northern hemisphere and return to North America, this fraction is small in comparison to more direct sources, such as the trans-Pacific transport from Asia (Government of Canada, 2012).

8.3 Ozone scenarios for 2010 to 2050

How will future O_3 levels 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 NO_X emissions? To answer such questions, the GAINS model (Amann et al., 2013) was used to generate a set of emissions under a range of assumptions about air pollution and climate policy.

The Current Legislation (CLE) and Maximum Technically Feasible Reduction (MTFR) scenarios used by HTAP 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 RCP6.0 scenario (until 2050) used by the Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment (AR5; van Vuuren et al., 2011) with regard to global fossil fuel carbon dioxide (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 CH_4 emissions, irrespective of 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 CH_4 emissions. Clim-CLE draws on the IEA '2 degrees' energy projections, which target 450 ppm CO_2 concentrations (IEA, 2012) through energy efficiency improvements and lower coal use, etc. Assumptions about air pollution legislation were adopted from Ref-CLE. The CO_2 emission trajectory is comparable to the RCP2.6 pathway used in IPCC AR5. 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' reductions in air pollutant emissions with progressive economic development (Amann et al., 2013). Therefore, for NO_X, nmVOC and CO some rebound effects are evident after 2030 (Fig. 33), while CH_4 emissions are nearly constant in Clim-CLE (Fig. 35).

Compared to earlier estimates, the global emissions show stabilisation or a slight decline after 2010 owing to recent control

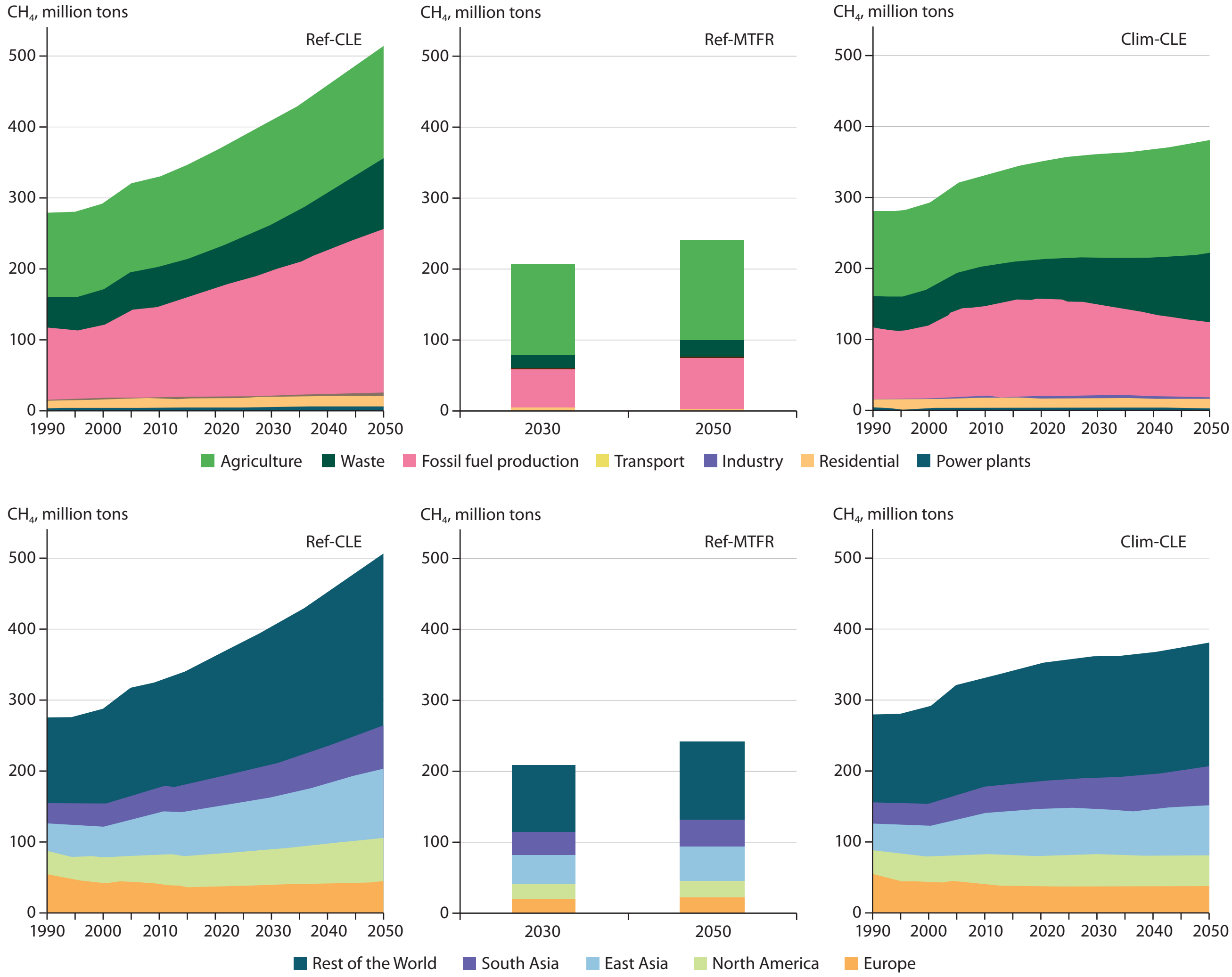


Figure 35. Methane emission scenarios: baseline (Ref-CLE and Ref-MTFR) and climate scenario (Clim-CLE) (Data from IIASA, www.iiasa.ac.at/web/home/research/researchPrograms/ECLIPSEv5a.html).

efforts in China (12th Year Plan and Action Plan, e.g., Zhao et al., 2013; Wang et al., 2014; Klimont et al., in prep.) (Fig. 33), and assume effective enforcement of existing legislation. At the same time, further strong growth in O_3 precursor emissions is expected in several other regions (Fig. 33).

The contribution of Europe and North America to global air pollutant and CH_4 emissions is declining. While Europe contributed 30% (NO_X), 23% (VOC), 16% (CO), and 19% (CH_4) of global 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 declines in contribution are seen for North America, except for CH_4. In contrast, contributions from 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 enormous potential for CH_4 emission reductions in the waste and oil and gas production sectors (Ref-MTFR and Clim-CLE, Fig. 35), while emissions from the agricultural sector are more difficult to reduce. Growth in CH_4 emissions mainly occurs outside the UNECE region.

The HTAP simulations indicate that, after an initial decrease in region-wide annual average O_3 concentrations in North America and Europe, O_3 may start increasing after 2020–2030, progressively driven by CH_4 (Fig. 36). Further ambitious pollution controls (MTFR) could reduce annual O_3 concentrations in Europe by 4 ppb by 2030 and 7 ppb by 2050, with roughly equal contributions from controls outside Europe and CH_4 emission controls, and a smaller contribution from controls in Europe. Although there is significant spread in the model results underlying these estimates, the difference between scenarios is generally greater than the spread. Ozone in summer, relevant for the growing season, declines more strongly than in winter, and stabilises at a reduction of about 3 ppb compared to the Ref-CLE scenario, but returns to 2015 levels by 2050. The Ref-MTFR scenario, which also includes several progressive CH_4 emission reductions, reduces summer O_3 by 8–9 ppb in 2050.

The HTAP analysis shows that in future, O_3 in Europe will become increasingly dependent on the development of emissions in other parts of the world. For the CLE case, O_3 reductions due to European policies are largely cancelled by increases in O_3 from CH_4 and by emissions outside Europe. Effective implementation of air pollution policies in emerging economies will lower the hemispheric O_3 concentrations in North America and Europe. Methane, an important greenhouse gas (GHG), is included in the basket of emissions of the Kyoto Protocol. Methane is not only important for climate, but also for reducing O_3 impacts on health and vegetation, and needs consideration in its own right.

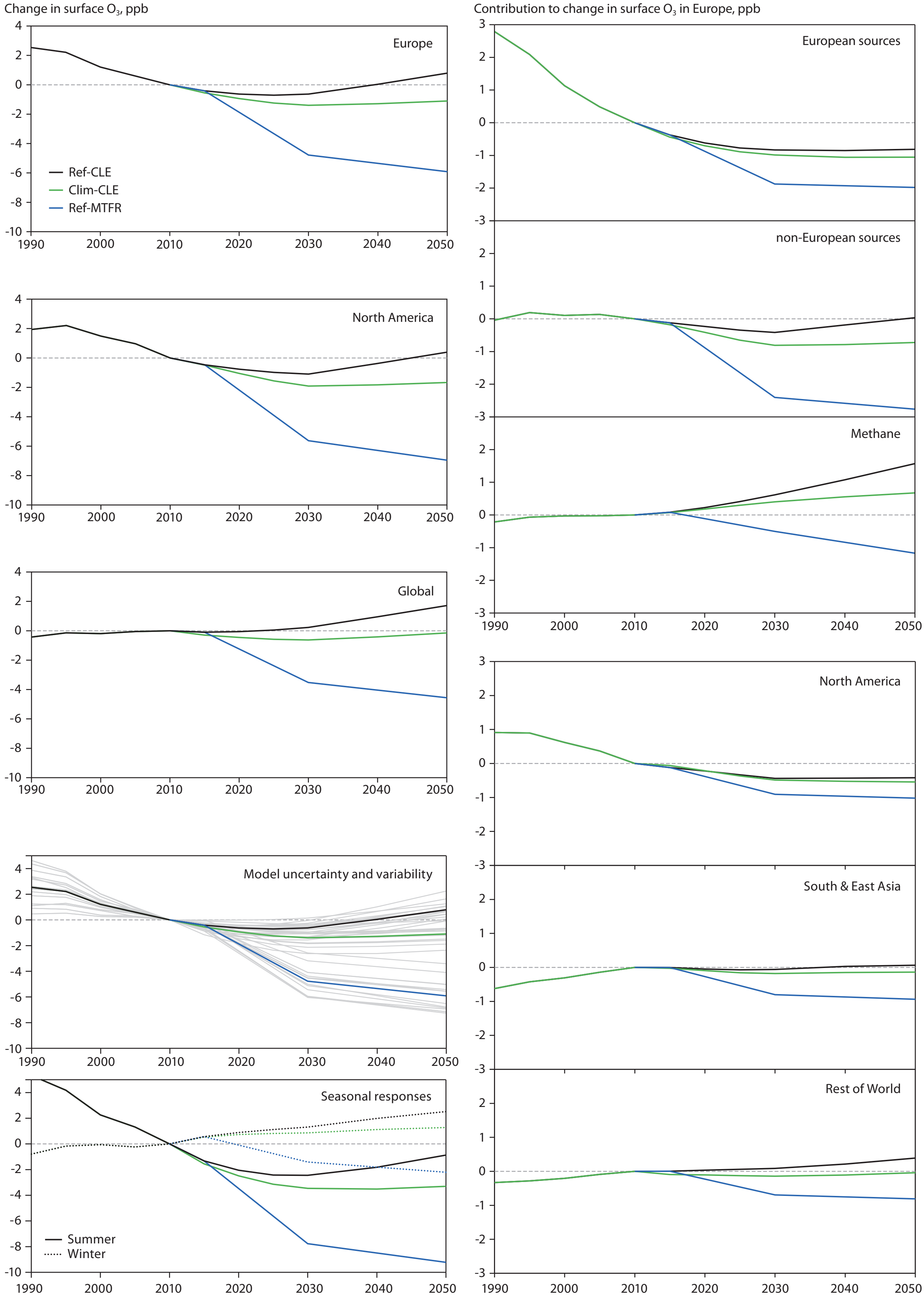


Figure 36. HTAP analysis of future annual surface ozone (O_3) changes in Europe, North America and the world, and the contributions to O_3 in Europe from European, North American, Asian, and Rest-of-the-world sources of nitrogen oxides (NO_X), carbon monoxide (CO) and volatile organic compounds (VOCs), and from global methane (CH_4) emissions. Bottom-left panels show model uncertainty and seasonal responses in summer (JJA) and winter (DJF). Emissions from ECLIPSEv5a database (Klimont et al., in prep.), and O_3 from HTAP simulations described by Wild et al. (2012).

8.4 Mercury's global reach

Mercury is emitted from both anthropogenic and natural sources, and due to its long residence time can be transported worldwide. The Minamata Convention on Mercury is a treaty to protect human health and the environment against the adverse effects of Hg. Methods and technical analysis by HTAP have contributed to a better understanding of the benefits for regions and countries of global cooperation, and options to further reduce Hg. Figure 37 shows the development of deposition in 2035 aggregated over six world regions for three future scenarios.

By 2035, current legislation is expected to lead to a 25% decrease in Hg deposition in North America and Europe, mainly due to internal policy (Ilyin et al., 2015). In this scenario, Europe's own contribution to Hg deposition declines from about 75% to 50%. In Africa, deposition would roughly stabilise, reflecting declining long-range contributions and increasing African sources. Deposition would increase by about 20% in East Asia, and by a staggering 100% in South Asia. New climate policies (NP) are beneficial for all continents, but particularly for East Asia, related to a declining reliance on coal burning in China. Implementation of all available technologies to reduce Hg emissions has the potential to reduce deposition by 75% or more relative to present-day emissions.

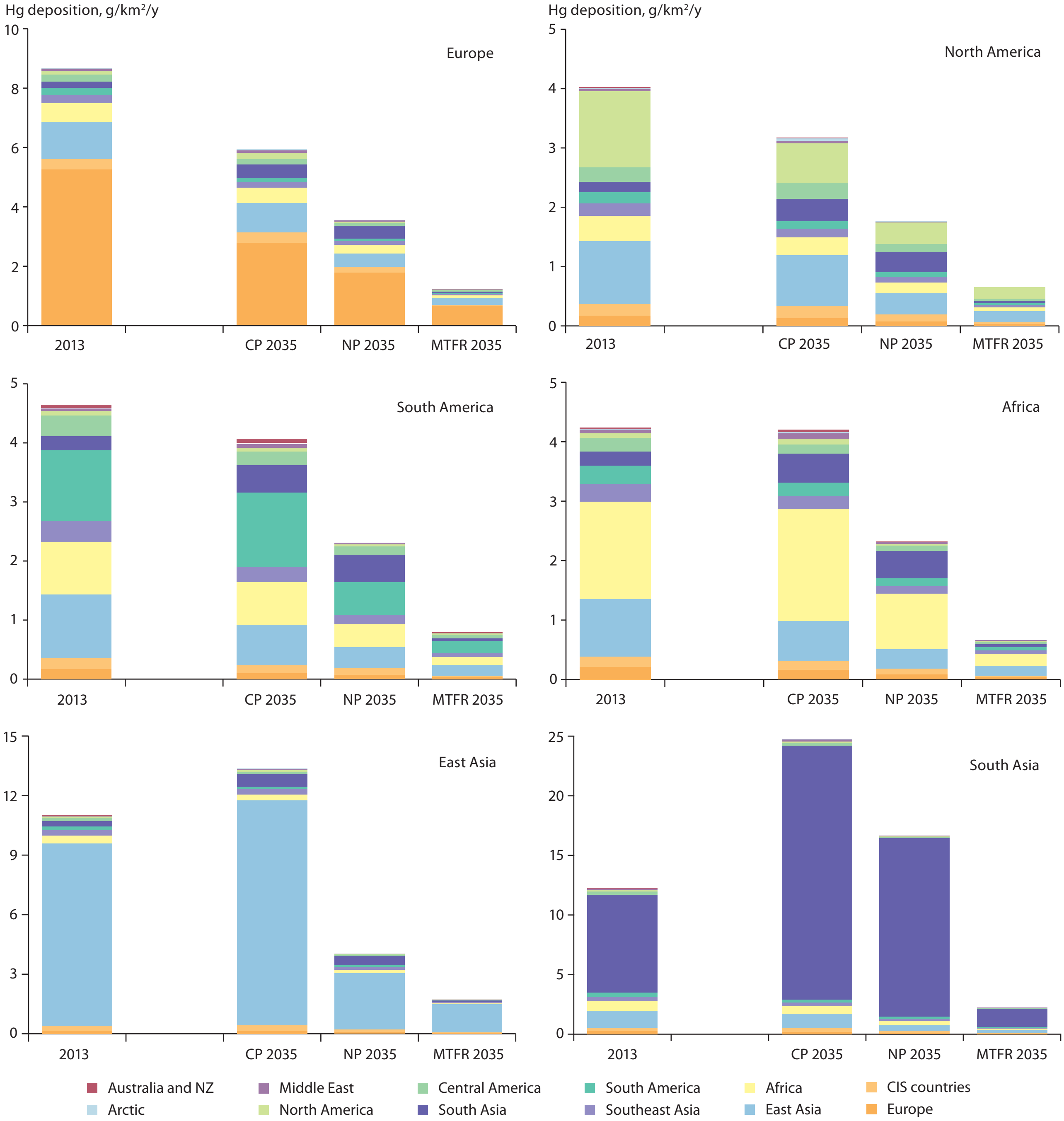


Figure 37. Mean mercury deposition from direct anthropogenic sources calculated by an ensemble of global models for three emission scenarios: CP, NP and MTFR. CP describes the situation whereby current policies and measures existing in 2010 are fully implemented (similar to CLE). NP (new policy) describes (similar to Clim-CLE) commitments to reduced GHG emissions, leading to further Hg reductions. MTFR shows maximum feasible reductions that could be achieved with currently known technologies. Deposition due to legacy/natural emissions is not included. Work has been performed within the GMOS project (www.gmos.eu) (Shatalov et al., 2015).

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

The costs of additional air pollution measures may be influenced by measures taken to reduce GHG emissions, increase energy security, reduce traffic congestion, increase traffic safety, reduce noise pollution or encourage green agriculture, all of which impact on air pollution. A combination of policies can offer significant synergies and is a way to balance potential trade-offs.

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.

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

9.1 Co-benefits for climate change

Many air pollution abatement measures have clear co-benefits for GHG emissions and climate change. To the extent that 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 limited attention to this aspect in the past, there is significant potential for win-win measures in the future, and they become more economically competitive with increasing costs of emission control (e.g., co-generation). Conversely, some of the technical emission controls employed in the past led to (slightly) higher CO_2 emissions (e.g., flue gas desulfurisation, denox), although this increase was often compensated by concomitant improvements in energy efficiency that emerge from better controlled process conditions.

Most air pollutants also affect climate during their (comparably short) residence in the atmosphere, either by enhancing or by masking temperature increase. At present, climate forcing from air pollutants is substantial (with a net cooling effect), and air pollution controls will alter the net balance (UNEP and WMO, 2011). To limit the rate of temperature increase in the coming decades air pollution policy could focus more on the abatement of air pollutants that have a both a warming effect and impose risks to human health and ecosystems: namely, black carbon and O_3 precursors, including CH_4 (Fig. 38). Together with aggressive CO_2-reduction strategies, abatement of such short-lived climate pollutants (SLCPs) would increase the probability of limiting warming to less than 2°C from pre-industrial levels this century.

Ozone formation is a good illustration of the positive feedbacks between climate change and air quality. By itself, O_3 would enhance warming. It would also reduce CO_2 uptake from the atmosphere by vegetation and forests and thus influence the development of atmospheric CO_2 levels. In turn a warmer climate could increase direct O_3 formation and release more biogenic O_3 precursors. Tackling O_3 precursors would have positive benefits for health, ecosystems and climate change mitigation.

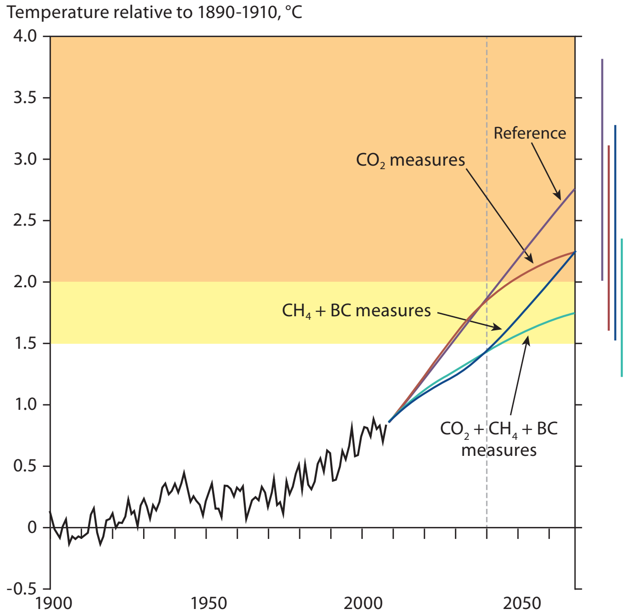


Figure 38. Role of methane (CH_4) and black carbon (BC) emission reductions as complementary strategies to carbon dioxide (CO_2) mitigation. Together with aggressive CO_2-reduction strategies they increase the probability of limiting warming to less than 2°C from pre-industrial levels this century (UNEP and WMO, 2011).

9.2 Co-benefits for air pollution

On the other hand, climate policy will 'automatically' influence emissions of air pollutants related to the use of fossil fuel. Reductions in fossil fuel use will not only reduce CO_2 emissions, but will also reduce emissions of SO_2, NO_X, nmVOC, PM and several heavy metals (such as Hg) and POPs (such as PAH, PCDD and HCB) (Fig. 39 and Box 7). This could either lead to a reduction in risk for human health and ecosystems, or to a reduction in the costs of meeting air quality standards. Such co-benefits for air pollution dominate the cost/benefit ratio of climate measures.

However, neither ambitious climate change policy nor air quality abatement policy will automatically yield co-benefits without integrated policies aimed at co-beneficial solutions, especially in the energy generation and transport sector. The combination of ambitious climate policy and maximum feasible air pollution emission reductions in these sectors would increase the probability of meeting the WHO air quality guideline values in Europe as well as the climate targets set during the 21st Conference of Parties to the UN Framework Convention on Climate Change.

Although most climate measures will help improve air quality, the use of biomass as a substitute for fossil fuels is an exception. This is especially true for residential wood burning, which contributes to indoor and outdoor PM exposure. Increased use of diesel engines could potentially lower fuel consumption compared to petrol-driven engines. However diesel-driven vehicles require exhaust cleaning techniques that themselves require energy and hence can increase fuel consumption and

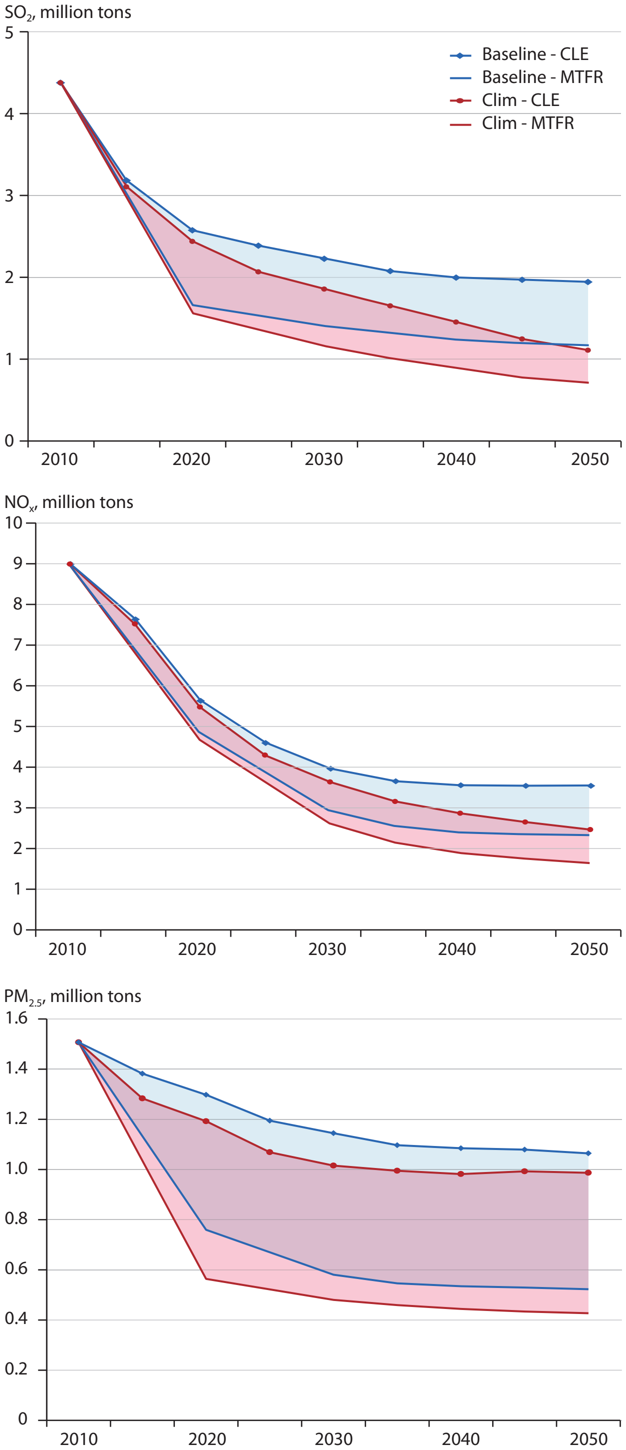


Figure 39. Scope for reducing emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_X) and fine particulate matter ($PM_{2.5}$) in the European Union, with and without climate measures (Amann, 2012).

reduce power generated. Even with exhaust cleaning, emissions of air pollutants, particularly NO_X from new diesel cars will still be higher than for petrol engines in real-world use. The air pollution consequences of increased use of biofuels in transport and of biomass in power generation would need careful assessment.

Reducing CO_2 emissions during energy generation by substituting fossil fuel with biomass might increase air pollutant emissions as increased biomass production will indirectly affect land use and emissions of biogenic VOC.

Box 7. Air quality projections in North America

Modelling analyses of the impact of future emission projections show reductions in ambient $PM_{2.5}$ concentrations between 2006 and 2030 in the United States and 2035 in Canada. Significant declines in ambient $PM_{2.5}$ concentrations are expected to occur in most Canada–US border region cities, with reductions of up to 35% in major US cities near the border and up to 25% in their Canadian counterparts. There is ongoing evidence that $PM_{2.5}$ is transported across the US–Canada border. However, for most cities in both countries, the dominant sources of $PM_{2.5}$ in 2020 will continue to be domestic emissions; overall, the transboundary influence is projected to be less in 2020 than 2006. For example, the influence of US emissions on $PM_{2.5}$ concentrations in Canadian cities near the border is projected to decrease by 2–10%, with the largest reductions occurring in eastern Ontario and southwestern Quebec. The exceptions are Abbotsford, British Columbia, where there is a small projected increase in US influence, and Saskatchewan and southwestern Manitoba where major shale oil production in the Bakken field in North Dakota have led to flaring.

Ongoing research is improving understanding of the bi-directional linkages between air quality and climate, which will allow air quality managers to understand both how climate change will impact on future air quality, and how air quality management programmes fit into overall strategies to mitigate the causes of climate change. Climate change is expected to have important negative impacts on air pollution, including increasing emissions of O_3 precursors, and PM formation from natural sources such as wildfires. Many air quality management actions that directly reduce emissions of some SLCPs, such as black carbon, have the co-benefit of reducing emissions of long-lived GHGs, and vice versa. For example, recent action such as the US EPA's Clean Power Plan and Canada's GHG regulations for coal-fired electricity generation are resulting in reductions in both climate pollutants and traditional air pollutants. Another example of this linkage is the use of wood or biomass in place of fossil fuels for heating, which reduces GHG emissions, but increases emissions of $PM_{2.5}$ and black carbon.

Short-lived climate pollutants include black carbon, CH_4, ground-level (tropospheric) O_3 and some hydrofluorocarbons (HFCs), defined by their relatively short atmospheric lifespans compared to longer-lived GHGs such as CO_2, and their warming impact on climate. Reducing emissions of SLCPs can help slow the rate of near-term climate warming as a complement to reducing CO_2 and other GHGs while, in the case of black carbon and O_3, also realising significant benefits for human health, agricultural productivity and ecosystems. Addressing black carbon is particularly important at northern latitudes because of its additional role in warming in the Arctic. SLCPs provide an important link between efforts to address air pollution and climate change. Canada and the Unites States are collaborating on SLCPs bilaterally, and with other international partners under several multilateral fora outside CLRTAP or the Gothenburg Protocol, including the Arctic Council and the CCAC. Current efforts to develop analytical tools that integrate climate pollutants and traditional air pollutants will improve the ability to identify optimal strategies to reduce climate pollutants and air pollution simultaneously.

9.3 Air quality and agriculture

Although climate policy includes limiting emissions of nitrous oxide (N_2O) and CH_4 from agriculture, NH_3 emissions will remain unaffected by climate policy. NH_3 emissions from agriculture and natural sources may even increase as a consequence of global warming (Fowler et al., 2015; Sutton et al., 2013). This would pose additional risks for human health (via the formation of secondary inorganic aerosols) and for ecosystems (via excess nitrogen deposition).

Besides the NH_3 and N_2O emissions to air, nitrogen losses during food production take place in the form of nitrate (NO_3) 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 practice have been formulated within CLRTAP and could – if complied with fully – reduce emissions of NH_3 in Europe by around 20%. Note that 80% of NH_3 emissions in Europe are generated by less than 10% of farms. The majority of the livestock is kept by a small number of industrial-sized farms. Ammonia abatement measures at such farms would be more cost-effective than measures at smaller farms. Many large farms are located around the North Sea (Box 8).

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

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

9.4 Air pollution policy contributes to sustainable development goals

Air pollution is linked to several sustainable development indicators. The WHO has identified air pollution as one of the top 10 causes of the global burden of disease. Air pollution policy can make a significant contribution to the sustainable development goals (SDGs), notably those to promote healthy lives and well-being in the world, to achieve food security and sustainable agriculture, to have safe and sustainable cities, to promote access to sustainable and modern energy sources and to protect terrestrial ecosystems.

While the SDGs are functional at the global scale, they provide little guidance for national and local decision makers on what could be done here and now. Air quality management could contribute to the achievement of several SDGs and thus offers an important and concrete instrument for gaining immediate success. Such successful examples could be communicated around the world. Air quality management could be one of the top priorities for governments in considering specific actions to realise SDGs.

Box 8. Hotspots for ammonia emissions

Ammonia emissions are not evenly spread across Europe (Fig. 40). 'Hotspots' occur in areas with high livestock densities, such as found in Ireland, UK, Benelux, Germany, Denmark, France, Switzerland and Italy. High nitrogen deposition in nature areas may also occur in these areas, but emissions from these areas contribute to ammonium nitrate and ammonium sulphate concentrations further away. The formation of these secondary aerosols depends on the availability of NO_X emissions (mainly from traffic) and SO_2 emissions (mainly from industry and power plants) in receptor areas.

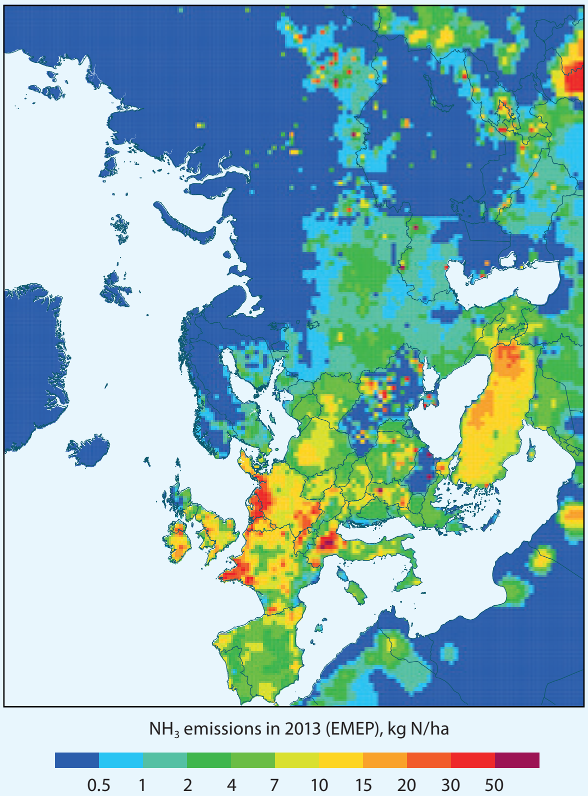


Figure 40. Ammonia emission densities in Europe for 2013 (EMEP – MSC-W).

10. 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 (e.g. Lim et al., 2012). 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.

But cities cannot reduce air pollution levels to the WHO guideline levels on their own. Even during high pollution episodes the contribution from sources outside the city is often dominant. Local air pollution risks are still predominantly a transboundary phenomenon in many European cities (Vieno et al., 2016). Reduction of exposure to fine particles ($PM_{2.5}$) would not only require a reduction in emissions of primary PM in cities (such as black carbon), but also of precursor emissions of secondary particles in a much wider area: SO_2, NO_X, NH_3 and VOCs.

CLRTAP could play a role in the exchange of knowledge and experience between cities. Collaboration and policy co-ordination within the EU and CLRTAP remains important in defining the most cost-effective ways to reduce health risks due to air pollution and the division of effort at the local, national and continental scale (Box 9).

Europe-wide emission reductions of precursor emissions are essential to meet the WHO annual guideline level for fine particles of 10 μg/m^3. Meeting this guideline level would reduce $PM_{2.5}$ concentrations by about a third, and would gain 1.6 million life years (and prevent 144,000 premature deaths) in the EU compared with the current (2012) situation (EEA, 2015b). Better nature protection due to lower nitrogen deposition would be a co-benefit.

Box 9. Possible action to move towards the WHO guideline value for $PM_{2.5}$

Convention level:

- Implement climate and energy targets
- Ensure that vehicle emission standards work in reality
- Implement emission standards for non-road mobile machinery, domestic stoves and installations for biomass burning
- Develop ammonia emission standards for large cattle farms.

National level:

- Ratify and implement CLRTAP protocols
- Implement climate and energy policies
- Implement effective control to maintenance schemes for vehicles
- Introduce scrappage schemes for old vehicles and motorcycles
- Enforce emission standards for farms and domestic stoves.

Local (urban) level:

- Introduce low emission zones to encourage early scrappage of old vehicles
- Introduce speed limits on highways near urban areas
- Encourage use of electric vehicles
- Improve infrastructure for public transport, cycling and walking
- Inform the public about air pollution from wood burning and ways to reduce pollution.

Long-term joint monitoring and modelling activities under CLRTAP have supported issue framing and have delivered data that were credible for all policymakers involved and could be used in the policy formulation phase. Integrated assessment modelling has been particularly useful in helping highlight the need for action, as well as the costs of taking no action (Box 10). The institutional setting provided by CLRTAP has been essential – 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 under CLRTAP is crucially dependent on 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 an important element of the success of the Convention (Raes and Swart, 2007; Reis et al., 2012).

Exchange of knowledge and experience between scientific and technical bodies under CLRTAP 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: O_3, Hg and some POPs are pollutants transported at the hemispheric scale. This necessitates a co-ordinated policy that goes beyond the current domain of CLRTAP to include major polluters in Asia.

Knowledge and experience gained under CLRTAP could be further shared with institutions working at a wider geographical scale, such as the IPCC, CCAC, WHO, UNEP, WMO, and Arctic Council, and the Minamata Convention or Stockholm Convention.

Box 10. Common understanding of complexity

An important factor for success in air pollution abatement was the development of a common knowledge base that included a scientific infrastructure aimed at joint monitoring and modelling programmes. The frequent exchange of information with policymakers created mutual trust and learning. In contrast to the first technology and cost-based protocols of the 1980s, an effect-orientated 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 air pollutants interact within the atmosphere, may lead to combined impacts, and often originate from the same sources (see Fig. 41). This made a substance-by-substance approach less efficient and was the reason behind the development of a so-called 'multi-pollutant multi-effect' approach, including SO_2, NO_X, NH_3, and VOC. The 1999 Gothenburg Protocol was the first protocol aimed at a cost-effective abatement of acidification, eutrophication and ground-level O_3 impacts on human health and the environment. The health impacts of fine particles were subsequently included in the analyses as were interactions with climate change.

Over almost 40 years, CLRTAP has developed an extensive international network of scientists of various disciplines. Frequent interaction between policymakers and scientists has been typical, enabling a long term-learning process, mutual trust and a common language. Joint measurement and modelling efforts have created a common understanding of air pollution issues. The integrated assessment model GAINS has played a central role in the communication between scientists and policymakers. GAINS includes the future expectations and the costs and impacts of policy options and makes it possible to identify the most cost-effective way to meet policy ambitions. The Task Force on Techno-economic Issues assists 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 to make it possible to compare models and their outcomes and so assess the long-range impacts of emission scenarios across continents: Europe, Asia and North America. This is a first step towards a co-ordinated approach to tackle hemispheric issues such as O_3 and Hg.

Complexity is also enhanced by the inevitable links between air pollution and climate change and has increased the need for closer co-operation with climate experts associated with UN organisations such as the United Nations Framework Convention on Climate Change (UNFCCC), the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC). Further co-operation on the issue of black carbon and other SLCPs is foreseen with UNEP, the Arctic Council and the Coalition on Clean Air and Climate.

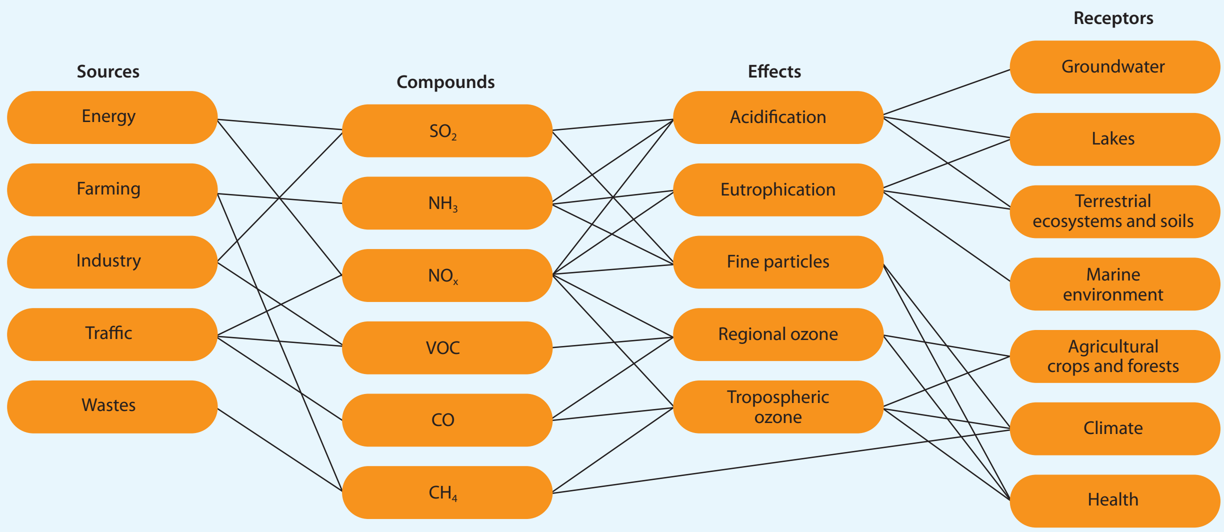


Figure 41. Relationships between sources and receptors of air pollution (based on Grennfelt et al. 1994).

A viable future for CLRTAP and its protocols depends on positive and vigorous participation by parties in all parts of the region, and on ensuring its extensive geographical coverage. Capacity-building activities implemented by UNECE with the support of several parties to CLRTAP are aimed at improved ratification, and implementation of and subsequent compliance with key protocols to the Convention. A positive development in recent years is the increased involvement of EECCA countries. Support to these countries is provided at the technical and policy level.

Efforts under CLRTAP have resulted in valuable science-policy interfaces and infrastructures and have formed an important knowledge base for emission inventories, models, observations and impact assessments of pollutants. These results are unique and would not have been otherwise accomplished. The infrastructure not only ensures compliance with protocols under CLRTAP, but also provides a valuable knowledge base available to support efforts under global agreements, such as the Stockholm Convention on POPs, the Minamata Convention on mercury and the Climate and Clean Air Coalition. Data and models developed under CLRTAP also provide valuable input to many other regional programmes and conventions, such as the regional sea conventions HELCOM and OSPAR, and the Arctic Monitoring and Assessment Programme under the Arctic Council.

10.1 Obstacles to ratification

There is limited scope for further reductions in SO_2 emissions within the EU. The maximum is a further 20% reduction through measures in industry, residential and commercial heating and reduced agricultural waste burning. In eastern European countries (Russia, Belarus, Ukraine) the scope for reduction is much greater: a 60% reduction could be achieved, mainly through abatement measures in coal and oil-fired power plants and in refineries. For NO_X and primary particulate matter the scope for emission reduction in eastern European countries is much greater than for the EU. Within the EU, additional abatement options would enable an average extension to life expectancy of 1.5 months compared to a baseline case, while the potential extension in eastern European countries is about four months. With additional abatement measures, average costs for each life-year gained in eastern European countries are about half those of an extra life-year gained in the EU. However, low average incomes in eastern European countries could prohibit ambitious policy measures: while the total costs of additional policy measures would be 0.05% of GDP in the EU, in eastern European countries such costs are much higher at more than 0.2% of GDP (Amann et al., 2011).

Technical annexes to the CLRTAP protocols provide clear guidance to EECCA countries in their process to ratify the Protocols and are seen as helpful in the design of national plans. The technical annexes create a level-playing-field for industries throughout the UNECE-region. This may prove important in free trade negotiations or in settling disputes between governments and industry within international treaties. However, the national emission ceilings (or national emission reduction obligations) that are part of the revised Gothenburg Protocol can be an obstacle to ratification in EECCA countries due to substantial uncertainties in their emission inventories and projections.

10.2 Further work

Further improving emission inventories, developing better projections and harmonising the monitoring of air quality as well as health and ecosystem impacts, will strengthen assessment and modelling capabilities in support of policy progress. Exploring synergies between air pollution policy at the local, regional and hemispheric scales, as well as with energy, transport and agricultural policy could help to identify additional cost-effective measures.

Capacity-building in EECCA countries focused on improving emission inventories and assessment of abatement potentials would be necessary to stimulate the ratification process. Improved emission data in EECCA countries could create more confidence that national emission reduction obligations are feasible. Nevertheless, it is unclear whether this is sufficient. Although the potential additional emission reduction percentages in EECCA countries are significantly larger than in the EU, and the costs per additional life-year saved are less, the additional abatement costs as a percentage of GDP to reach the same emission factors as in the EU would be much higher. Without financial or technological support this could be seen as a reason to request more time for implementing measures in EECCA countries.

Annex: 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, 2015.

Total SO_X (as SO_2) emissions, kt	1990	1995	2000	2005	2010	Difference 2010–1990
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	1099.0	1295.2	861.3	776.4	386.8	-65%
Canada	3057.2	2593.0	2414.2	2200.4	1370.7	-55%
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	1309.0	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	1288.2	965.9	628.0	461.1	285.3	-78%
Georgia	276.1	72.6	11.6	4.9	6.4	-98%
Germany	5307.3	1704.1	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	1800.0	1326.8	753.6	406.6	214.9	-88%
Kazakhstan	2499.4	1846.0	1498.8	1827.4	2465.7	-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	3210.0	2255.2	1451.5	1217.4	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	1336.5	1161.0	817.8	641.9	364.3	-73%
Russian Federation – European Part	4329.9	2268.2	1807.2	1910.8	1521.6	-65%
Russian Federation – Asian Part	1838.3	1141.9	1237.2	1666.0	1982.7	8%
Serbia	489.7	509.9	474.0	436.4	422.2	-14%

Total SO_X (as SO_2) emissions, kt	1990	1995	2000	2005	2010	Difference 2010–1990
Country emissions						
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	2091.3	1798.5	1463.9	1254.8	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%
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	1750.3	1889.8	2334.5	2106.0	2561.0	46%
Turkmenistan	128.7	81.4	101.2	129.8	212.5	65%
Ukraine	4607.0	2397.6	1390.1	1073.4	1122.8	-76%
United Kingdom	3681.5	2365.6	1217.3	709.6	427.6	-88%
United States of America	20,935.0	16,891.0	14,830.0	13,145.2	6951.0	-67%
Uzbekistan	517.5	419.7	507.1	659.8	991.1	92%
Total Country emissions	**68,179.3**	**47,865.4**	**37,927.1**	**33,550.2**	**24,777.2**	**-64%**
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	1054.1	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	1269.0	1553.9	131%
North Africa	199.3	235.6	303.5	361.0	487.1	144%
Total Area emissions	**2743.4**	**3062.9**	**3446.1**	**3990.4**	**3982.6**	**45%**
Total (Countries and Areas)	**70,922.7**	**50,928.3**	**41,373.2**	**37,540.6**	**28,759.8**	**-59%**

Data were downloaded from www.ceip.at 5 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
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%
Canada	2851.3	2785.0	2867.8	2544.9	2091.2	-27%
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	1911.2	1745.3	1610.0	1430.1	1096.4	-43%
Georgia	120.6	28.7	22.6	25.0	31.0	-74%
Germany	2882.3	2167.1	1925.4	1573.2	1333.7	-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	2047.3	1920.0	1455.8	1244.3	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	1010.0	1063.1	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	4641.4	3015.0	2777.3	2979.5	2390.9	-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%

Total NO_X (as NO_2) emissions, kt	1990	1995	2000	2005	2010	Difference 2010–1990
Country emissions						
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	1269.7	1315.8	1299.6	1322.5	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%
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	2134.6	1201.8	888.3	875.0	690.1	-68%
United Kingdom	2880.4	2316.1	1797.7	1586.5	1123.0	-61%
United States of America	23,023.0	22,997.0	20,581.0	19,343.7	14,221.0	-38%
Uzbekistan	151.6	123.0	148.5	193.3	290.3	92%
Total Country emissions	**53,733.3**	**47,788.7**	**42,751.1**	**40,691.5**	**32,304.2**	**-40%**
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	1280.0	1430.0	1580.0	1767.5	1478.2	15%
North Sea	553.0	615.2	677.4	755.2	635.2	15%
North-East Atlantic Ocean	763.8	855.5	950.2	1065.6	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	**3153.5**	**3540.1**	**3943.3**	**4466.4**	**3995.7**	**27%**
Total (Countries and Areas)	**56,886.8**	**51,328.8**	**46,694.4**	**45,157.9**	**36,299.9**	**-36%**

Data were downloaded from www.ceip.at 5 October 2015; Germany: Former German Democratic Republic and Former Federal Republic of Germany.

Total NH_3 emissions, kt	1990	1995	2000	2005	2010	Difference 2010–1990
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%
Canada	398.5	467.8	490.5	493.1	462.1	16%
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	1191.4	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%

Total NH_3 emissions, kt	1990	1995	2000	2005	2010	Difference 2010–1990
Country emissions						
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%
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%
United States of America	3975.0	4289.0	3348.0	3578.5	3655.0	-8%
Uzbekistan	54.5	44.2	53.4	69.5	104.3	92%
Total Country emissions	**13,114.1**	**11,761.4**	**10,308.9**	**10,393.8**	**10,483.8**	**-20%**
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)	**13,645.8**	**12,410.4**	**11,092.6**	**11,385.3**	**11,709.4**	**-14%**

Data were downloaded from www.ceip.at 5 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
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%
Canada	4377.0	3920.3	3308.2	2705.1	2308.3	-47%
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	2469.1	2062.4	1681.0	1239.0	874.3	-65%
Georgia	104.8	62.3	64.9	58.9	62.6	-40%
Germany	3392.4	2027.7	1599.5	1340.2	1238.8	-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	1936.0	1974.4	1523.5	1242.1	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	3772.1	2847.7	2691.9	2684.1	2245.7	-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%

Total nmVOC emissions, kt	1990	1995	2000	2005	2010	Difference 2010–1990
Country emissions						
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	1023.6	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%
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	1246.5	651.6	574.5	595.0	481.3	-61%
United Kingdom	2721.1	2202.5	1566.7	1136.1	855.2	-69%
United States of America	21,871.0	19,996.0	15,887.0	14,411.2	13,579.0	-38%
Uzbekistan	53.4	43.3	52.3	68.1	102.2	92%
Total Country emissions	**52,739.3**	**44,262.2**	**36,747.3**	**32,794.7**	**29,932.7**	**-43%**
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)	**53,213.6**	**44,814.8**	**37,397.0**	**33,605.5**	**30,876.6**	**-42%**

Data were downloaded from www.ceip.at 5 October 2015; Germany: Former German Democratic Republic and Former Federal Republic of Germany.

Total $PM_{2.5}$ emissions, kt	2000	2005	2010	Difference 2010–2000
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%
Canada	1186.4	1173.1	1384.5	17%
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%

Total $PM_{2.5}$ emissions, kt	2000	2005	2010	Difference 2010–2000
Country emissions				
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%
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%
United States of America	6153.8	4593.5	4513.0	-27%
Uzbekistan	101.2	131.7	197.8	95%
Total Country emissions	**11,398.4**	**9770.4**	**10,063.4**	**-12%**
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)	**11,809.8**	**10,251.7**	**10,558.0**	**-11%**

Data were downloaded from www.ceip.at 5 October 2015; Germany: Former German Democratic Republic and Former Federal Republic of Germany.

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Acronyms and Abbreviations

AMAP	Arctic Monitoring and Assessment Programme
BaP	Benz[*a*]pyrene
CAD	Canadian dollar
CCAC	Climate and Clean Air Coalition
CCC	Chemical Coordination Centre (EMEP)
CCE	Coordination Centre for Effects
Cd	Cadmium
CEH	Centre for Ecology and Hyrdology
CEIP	Centre for Emission Inventories and Projections (EMEP)
CH_4	Methane
CIAM	Centre for Integrated Assessment Modelling at IIASA (EMEP)
CLE	Current Legislation
Clim-CLE	Current legislation scenario for air pollution including climate mitigation measures
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
EC	European Commission
EC4MACS	European Consortium for Modelling of Air Pollution and Climate Strategies
ECLIPSE	Evaluating the climate and air quality impacts of short-lived pollutants
EDGAR	Emission Database for Global Atmospheric Research
EEA	European Environment Agency
EECCA	Eastern Europe, the Caucasus and Central Asia
EMEP	European Monitoring and Evaluation Programme
EU	European Union
EU28	European Union, 28 member states
EUR	Euro
GAINS	Greenhouse gas - Air pollution Interactions and Synergies model
GDP	Gross Domestic Product
GHG	Greenhouse gas
GMOS	Global Mercury Observation System
HCB	Hexachlorobenzene
HELCOM	Helsinki Convention
Hg	Mercury
HTAP	Task Force on Hemispheric Transport of Air Pollution (EMEP)
ICP	International Cooperative Programme
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
INERIS	Institut national de l'environnement industriel et des risques
IVL	Swedish Environmental Research Institute
JRC-IES	Joint Research Centre of the European Commission - Institute for Environmental Sustainability
MACC	Monitoring Atmospheric Composition & Climate Consortium
MSC-E	Meteorological Synthesising Centre-East (EMEP)
MSC-W	Meteorological Synthesising Centre -West (EMEP)
MTFR	Maximum (Technically) Feasible Reduction
NH_3	Ammonia
nmVOC	Non-methane volatile organic compounds
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration (US)
NO_X	Nitrogen oxides
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
OSPAR	OSPAR Convention
Pb	Lead
PCB	Polychlorinated biphenyl
PCDD/Fs	Dioxins and furans
PEMA	Pollutant Emission Management Area
PM	Particulate matter or: fine particles
$PM_{2.5}$	Particles ≤ 2.5μm in diameter
PM_{10}	Particles ≤ 10μm in diameter
POPs	Persistent organic pollutants
ppb	Parts per billion
ppm	Parts per million
Ref-CLE	Current legislation scenario for air pollution
Ref-MTFR	Maximum technically feasible reduction scenario for air pollution
RIVM	Netherlands National Institute for Public Health and Environment
SDGs	Sustainable Development Goals
SEE	South East Europe
SLCP	Short-lived climate pollutant
SO_2	Sulphur dioxide
TFMM	Task Force on Measurement and Modelling (EMEP)
TFRN	Task Force on Reactive Nitrogen (EMEP)
Tg	Teragram = 1 million tons
Ton	Metric ton = 1000 kg
TSAP	Thematic Strategy on Air Pollution (EU)
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UN FCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compounds
WEOG	Western European and Other (Stockholm Convention effectiveness evaluation region)
WGE	Working Group on Effects of the Air Convention
WHO	World Health Organization

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