Please send written comments/additions to rob.maas@rivm.nl before 8 September

III. Emission, concentration and deposition trends

Emission trends

9. Over the last 20 years, stricter emission standards have to led to decreased emissions of SO_2, NO_x and PM2.5. Moreover, emission reductions were realized due to fuel switching from coal to natural gas fuels, particularly in the residential sector. The impact of reduced use of coal in electricity generation is ongoing and is accentuated by the increased use of renewables. By contrast, modest ammonia emission reductions over the past 20 years have primarily been driven by targeted emissions reduction policies like covered manure storage, low emission spreading of manure, emission standards for large stables, etc..

Table 1 shows the trends in these emission reductions by region.

Pollutant	Western Europe (EU27+UK+EFTA) 2000-2019	EECCA 2000-2019	CAN-US 2005-2019
Sulpur dioxide	-82%	-22%	CAN: -66% US: -86%
Nitrogen oxides	-48%	- 1%	CAN: -29% US: -57%
Ammonia	-12%	+ 10%	CAN: -3% US: + 5%
Volatile organic compounds	-43%	+ 11%	CAN: -27% US: -23%
PM2.5	-35%	-15%	CAN: -29% US: -18%

Table 1 – Trends in emissions by region official reported to CEIP *Note: The latest available data provided by the Parties has been used. The table is based on an emission dataset gap-filled by CEIP. Documentation of gap-filling methods is available at https://www.ceip.at/ceip-reports*

12. Emission trends are calculated on the basis of reported emission inventories. The emission inventories submitted by Parties differ in quality, and technical reviews have identified those Parties whose submissions need improvement. There have been significant improvements in the completeness of reporting in recent years, with 47 Parties submitting inventories in 2022. However, submissions from 9 Parties were incomplete, and 9 Parties did not provide an Informative Inventory Report.

13. When developing emission inventories, the initial focus is on completeness before accuracy is improved. Even if completeness issues are addressed, substantial improvements will be needed in numerous national emissions inventories before the accuracy of emission estimates across Parties will be at “good practice” quality levels.

14. Reported emissions entail uncertainty margins of 10 per cent to over 100 per cent. In general, the trend in emissions is less uncertain than the absolute levels. The trend in emissions is comparable to the trend in measured concentrations though in some cases, there are unexplained divergences (see Table 2).

15. BC emissions are reported on a voluntary basis, with 40 Parties providing BC emission estimates. Significant inconsistencies exist between estimates, suggesting that the accuracy and completeness of the submissions need to be improved. Emission

trends are expected to be more reliable, and data for the 27 European Union member States show emissions halving from 1990 to 2018 and for Canada they have decreased by 22% since 2013. Some of the reductions in Europe, the United States of America and Canada have come from reductions from diesel vehicles. The residential sector is also a source of black carbon emissions. For Europe, the residential sector is becoming the main source. For the United States of America, around 8% of emissions are from residential solid wood burning.

16. The Air Pollutant Emission Inventory Guidebook of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) and the European Environment Agency (EEA) is widely used and is considered to be comprehensive in its scope and content. However, there are a number of improvements that could be made, in particular, regarding funding mechanisms, collaboration and methodologies for lower priority pollutants. There are also decisions that must be made on metrics for BC and inclusion of condensables and semi-volatile particles before guidance can be updated. Updated guidance should aim at properly characterizing real-world emissions for the different wood and other solid fuel burning appliances and their operating conditions. In addition, emissions methodologies in the Guidebook need to better account for the influences of climate change. A decision on the inclusion of condensables for domestic solid fuel burning must take due account of the policy implications involved, such as compliance, information that is not yet fully available at the time of the completion of this review.

Concentration and deposition trends

17. Pollutant concentration trends generally followed the decreasing emission trends in the EMEP region. For the United States and Canada, data for comparable indicators to those produced for the EMEP-region still proved difficult to obtain. Between 2000 and 2019, wet deposition of oxidised sulphur declined by 77% in the United States PEMA-region and by 68% in the Eastern half of Canada. Oxidised nitrogen deposition declined by 35% in the PEMA-region and by 50% in Canada. Ammonia and particulate ammonium increased in the North-Central region of the United States.

	2000-2019
Sulphur dioxide concentrations	-74%
Nitrogen dioxide concentrations	-24%
Total nitrate concentrations (nitric acid plus particulate nitrate)	-38%
Reduced N concentrations (ammonia and particulate ammonium)	-28%
PM2.5 concentrations	-46%
Particulate sulphate concentrations	-61%
Particulate nitrate concentrations	-38%
Particulate ammonium concentrations	-49%
Wet deposition of oxidised sulphur	-60%
Oxidised nitrogen deposition	-26%
Wet deposition of Ammonium	-6% (since 2006)

Table 2 – Trends in annual average concentrations and depositions in the EMEP-region

18. From around 1990 onwards, the total emissions of NO_x declined significantly in Europe, followed by reductions in oxidised nitrogen concentrations. After 2008, measured and modelled concentration trends diverge from the reported emission trends, which might indicate that the effectiveness of NO_x-abatement measures (the Euro-standards for vehicles) is overestimated in the reporting of emissions.

19. Due to the limited availability of nitric acid and sulphate, ammonium particles (secondary PM) in air declined and as a consequence more ammonia remained in the air as gas and was deposited closer to the emission source. In the EMEP region, the majority of sites monitoring concentrations in air show no declining trend for NH_3.

20. Ground-level ozone (O_3) is a secondary pollutant that results from complex physico-chemical mechanisms. Therefore, observed average concentrations do not change at the same rate as reductions in regional precursor emissions (NO_x and non-methane volatile organic compounds (NMVOCs)), and are influenced by other factors such as climatic parameters, hemispheric transport and global CH_4 emissions. In Europe, O_3 peaks have declined systematically (by around 10 per cent between 2000 and 2019). The health-related SOMO35 (for O_3, the sum of means over 35 parts per billion (daily max. 8-hour)) indicator decreased by about the same magnitude. The annual average O_3 concentrations remained constant and tended to increase in urban areas.

21. For carbonaceous aerosols, including BC, observed and modelled trends for 15 EMEP stations show an average reduction of 4 per cent per year.

22. Around half of the EMEP sites have recorded exceedances of the 2005[1] World Health Organization (WHO) air quality guidelines for $PM_{2.5}$ in recent years. Air quality data reported by EU-Member States and collated in the annual EEA Air Quality in Europe reports, as well as EMEP Meteorological Synthesizing Centre-West model simulations show a decrease in exceedances over the past two decades. Local air quality can be strongly influenced by regional and even transboundary air pollution processes. Furthermore, urban exceedances and associated health risks are a stimulating driver for additional air quality policy, including for countries that are not parties to the Protocol (average population weighted exposure still has to be calculated).

23. The influence of transcontinental transport of PM on sulphur and Nitrogen concentrations and deposition in Europe, Canada and the United States is relatively minor, though not insignificant (see also section XII on Canada and the United States). Wildfires and wind-blown dust originating outside Europe substantially influence concentration levels during episodes (typically a few times a year).

24. While the 50x50 EMEP-model resolution was representative for the regional background, the new high-resolution model can also represent urban background concentrations. Exceedances of critical loads are slightly higher in the new model. The observational network is dominated by sites in the European Union and EEA-countries and has hardly coverage in Eastern Europe, the Caucasus, Central Asia and Western Balkan area. Thus, measured trends are less representative for these sub-regions. Current monitoring and modelling systems used under the Convention to calculate ambient concentrations and deposition levels should be assessed further (more information expected in 2022–2023) to see if they are fit for use in optimized reduction allocations and dealing with the increased variation in highly and less polluted regions that becomes visible from finer resolution approaches.

IV. Effects on human health and natural ecosystems, materials and crops

28. Updated WHO air quality guideline values, relative risk factors, as well as no-effect/counterfactual values, became available in late 2021. These will form the basis for new assessments of mortality and morbidity risks for $PM_{2.5}$, NO_2 and O_3 in the

[1] Next step in the review is to update taking into account the updated WHO guidelines (WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021).

EMEP region. Preliminary EMEP assessments show a relatively high population exposure to $PM_{2.5}$ in large cities and in industrial areas, in particular in countries of Eastern Europe, the Caucasus and Central Asia. Health risks of $PM_{2.5}$ will include exposure to secondary inorganic particles, as well as secondary organic particles caused by emissions of NH_3 and VOCs.

29. Aquatic and terrestrial ecosystems have shown evidence of recovery from acidification since the 1990s. Moreover, many sites covered by the International Cooperative Programme on Assessment and Monitoring of the Effects of Air Pollution on Rivers and Lakes show an increase in biodiversity at sites with the most pronounced chemical recovery. Empirical results are in line with the exceedances of the critical load for acidification, which were reduced from 14 per cent of the sensitive terrestrial and aquatic ecosystem area in Europe in 2000 to only 4 per cent in 2019.

30. Critical loads for eutrophication by N deposition remained exceeded for 64 per cent of the sensitive ecosystem area in Europe in 2019, down from 75 per cent in 2000. Exceedances are expected to decrease only moderately in the coming decade

31. Both acidification and eutrophication are dominated by ammonia emissions from agricultural sources. NOx-emissions are expected to decline further as a result of climate and energy measures and penetration of zero-emission vehicles._Additional emission reductions especially of ammonia are necessary to allow ecosystems recovery and prevent, inter alia, effects on nutrient imbalances in trees, on surface water and groundwater quality, on biodiversity, as well as on the resilience of forests to stress factors such as drought or insect infestation.

32. The results from the ecosystems monitoring network under the Working Group on Effects provide evidence on the link between critical load exceedances and empirical impacts, and confirm that emission abatement actions are having effects on critical load exceedances and therefore reduce impacts.

33. To assess the potential recovery of ecosystems, according to future emission scenarios, the use of dynamic modelling tools can be considered in the coming years. To assess biodiversity and the loss of specific species that are sensitive for eutrophication, new models will have to be explored.

34. An ad-hoc marine group under the Working Group on Effects, led by Germany, was recently established to develop options to include marine ecosystem protection in future emission reduction strategies in cooperation with the Baltic Marine Environment Protection Commission and the Convention for the Protection of the Marine Environment of the North-East Atlantic.

35. Model results suggest that the phytotoxic O_3 dose for deciduous forests declined over the period 2000–2016 by approximately 0.7 per cent per year at EMEP O_3 stations. The phytotoxic O_3 dose for crops shows no significant decline for the majority of sites. Based on current knowledge, O_3 pollution was responsible for a reduced wheat grain yield of, on average, 9.9 per cent in the northern hemisphere in the period 2010–2012.[2] Projections based on current climate and energy policies (Representative Concentration Pathway 4.5) show that O_3 risks to biodiversity will still occur by 2050, as O_3 exposure will remain similar to that in 2000.[3] Similarly, projections show that there will still be a potential risk for a significant effect of O_3 on the biomass increment of trees.

36. Corrosion and other damage on materials and cultural heritage has decreased significantly since the early 1990s due to the decrease of SO_2 levels. After 1997, the

[2] Gina Mills and others, “Ozone pollution will compromise efforts to increase global wheat production”, *Global Change Biology*, vol. 24, No. 8 (August 2018), pp. 3560–3574.

[3] Jürg Fuhrer and others, “Current and future ozone risks to global terrestrial biodiversity and ecosystem processes”, *Ecology and Evolution*, vol. 6, No. 24 (December 2016), pp. 8785–8799.

decrease in corrosion became more modest; currently a constant level seems to have been reached.[4] Carbon steel and copper corrosion decreased more pronouncedly in urban areas even after 1997. For soiling, there is no decreasing trend after 1997 and, consequently, many areas in Europe are above acceptable levels. The main pollutant responsible for soiling of materials is PM.

4 Johan Tidblad and others, ICP Materials Trends in Corrosion, Soiling and Air Pollution (1987–2014), *Materials*, vol. 10, No. 8 (August 2017).