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Executive Body for the Convention on Long-range Transboundary Air Pollution

Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe

Working Group on Effects

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Item 2 of the provisional agenda
Matters arising from recent meetings of the Executive Body and its subsidiary bodies and activities of the Bureaux of the Steering Body and the Working Group on Effects

2024 Joint progress report on policy-relevant scientific findings

Note prepared by the Chairs of the Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe and the Working Group on Effects, in cooperation with the secretariat

Summary

The present report was drafted by the Chairs of the Working Group on Effects and the Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, in cooperation with the secretariat to the Convention on Long-range Transboundary Air Pollution. The review of recent scientific findings is based on the information provided by the lead countries and the programme centres of the international cooperative programmes, and is submitted in accordance with the 2024–2025 workplan for the implementation of the Convention (ECE/EB.AIR/154/Add.1).

I. Introduction

1. The present report was compiled by the Chairs of the Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) and the Working Group on Effects, in accordance with the 2024–2025 workplan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR/154/Add.1). The report reflects achievements during 2023 and 2024 and was prepared with support from the secretariat and scientific subsidiary bodies.

II. Scenarios for the upcoming revision of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012

2. The Working Group on Effects and EMEP are currently cooperating with the Working Group on Strategies and Review in setting up scenarios for integrated assessment modelling that could be used as a basis for the revision of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012 (Gothenburg Protocol). The scenarios developed for the review of the Gothenburg Protocol will be updated in 2024 (see also para. 45) and will define the scope for further potential emission and impact mitigation. On this basis, a limited set of optimized scenarios with a multi-pollutant, multi-effect approach considering effects on health, ecosystems and biodiversity will be developed. A collective (United Nations Economic Commission for Europe (ECE) regionwide) target to reduce air pollution-related health and ecosystem impacts by 50 per cent by 2040, compared to 2015, has been suggested as a starting point. For ecosystems, an optimized scenario aiming at equal improvement for the countries will be developed. This scenario will be based on country-submitted critical load maps, supplemented with data from the background database of the Coordination Centre for Effects (CCE). For biodiversity, the updated empirical critical loads will be used in combination with a receptor map for the corresponding European Nature Information System (EUNIS) nature types. CCE has provided an updated European-scale receptor map to the Centre for Integrated Assessment Modelling (CIAM). It is expected that the optimization will be equal in reduction in pressure for all nature types because they are habitats for different species and must be protected to protect biodiversity.

3. Based on calculated concentration and deposition fields from the optimized scenarios, further analysis can be carried out and used as a basis for comparing scenarios. Such analysis is traditionally called “ex-post analysis” because it is performed after the optimized scenarios have been developed. This analysis can include a wider range of pollutants and effects, both at the European scale and for areas where more detailed local information and/or calibrated models are available. The analysis will also include a wider range of recipients such as materials, crops and sea, and can include cost-benefit analysis. For biodiversity, the analysis will include the use of dynamic soil geochemistry/plant occurrence models to calculate the pressure on typical plant species for each nature type. The scientific background and assumptions that will frame the integrated assessment modelling work for the revision of the Gothenburg Protocol are described in a policy brief that should facilitate the dialogue between policy and science communities. This document will be updated with integrated assessment modelling results during the revision process.[1]

III. Air pollution effects on health

4. Work on the consolidation of existing evidence on health outcomes of air pollution has continued, particularly on selection of concentration-response functions and associated information for health risk assessment, through the Estimating the Morbidity from Air Pollution and its Economic Costs (EMAPEC) project and the Health risks of air pollution in Europe (HRAPIE)-2 project. At a recent meeting (Bonn, Germany, 15–16 April 2024), experts discussed the preliminary results of commissioned systematic reviews on long-term exposure to air pollution and all-cause and cause-specific mortality, as well as other evidence and associated information necessary for health risk assessment. These reviews have been submitted to a peer-reviewed journal. In relation to EMAPEC, a review of systematic reviews on long-term exposure to air pollution and morbidity outcomes will be published in 2024.

5. Human health effects associated with the selected air pollutants (benzene, arsenic, cadmium, nickel and mercury) that were not covered by the 2021 World Health Organization (WHO) global air quality guidelines were reviewed and summarized in a WHO report.[2] The

[1] The latest version was prepared for the sixty-second session of the Working Group on Strategies and Review and is available at https://unece.org/environment/documents/2024/05/informal-documents/agenda-item-2-draft-policy-brief-potential-targets.

[2] Available at https://iris.who.int/handle/10665/375606.

findings indicate that there is insufficient new evidence to support changes of current air quality guidelines. The report identified knowledge gaps and areas for future research.

6. Work on tools for health and economic impact assessments, mainly AirQ+ and Climate Change Mitigation, Air Quality and Health (CLIMAQ-H) continued, with updated versions (CLIMAQ-H) or new language versions (AirQ+: Spanish version launched in February 2024) of the tools being made available. Capacity-building efforts continued, with a hands-on practical training session on air quality and health for experts from Kyrgyzstan and Kazakhstan being held in Bishkek in December 2023.

IV. Air pollution effects on materials and cultural heritage

7. The International Cooperative Programme on Effects of Air Pollution on Materials, including Historic and Cultural Monuments (ICP Materials) conducts repeated exposure studies. A new exposure study will start in 2024. In addition to the materials used for trend analysis (carbon steel, zinc (Zn) and limestone), relatively novel metallic coatings (Zn-aluminium (Al)-magnesium (Mg)), used, for example, in support of solar panel structures, will be exposed.

8. The effect of particulate matter (PM) from non-exhaust emissions (brake wear, tire wear, road wear and road dust resuspension) is not expected to decrease in the same way as for exhaust emissions. Non-exhaust emissions contain many different elements that can potentially play an important role in the initiation of corrosion and will therefore be studied in depth for these metallic coatings, as well as for other metallic materials.

9. ICP Materials also conducts studies of selected United Nations Educational, Scientific and Cultural Organization (UNESCO) sites and air pollution effects on corrosion and soiling of the materials contained in monuments.

V. Air pollution effects on ecosystems and biodiversity

A. Forests

10. For decades, the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) has been collecting data on the deposition of acidifying, buffering and eutrophying substances in European forests by collecting precipitation below the tree canopy. Sulfate throughfall deposition has substantially decreased since the start of the monitoring nearly 40 years ago, and today medium (>3–6 kg S ha^{-1} yr^{-1}) and high (>6 kg N ha^{-1} yr^{-1}) sulfate deposition is mainly restricted to areas close to large point sources and in Central Europe (Austria, Czechia, Germany, Poland and Slovakia) and South-Eastern Europe (Bulgaria, Croatia, Greece, Romania and Serbia). Medium (>10–20 kg N ha^{-1} yr^{-1}) and high (>20 kg N ha^{-1} yr^{-1}) throughfall deposition of inorganic nitrogen is still observed throughout Central Europe, with high ammonium deposition having been measured in a wider area than NO_x. A significant decrease in nitrogen emissions across Europe was detected in 2019–2020 and might be associated with the coronavirus disease (COVID-19) pandemic lockdown.

11. Two studies at the European level provided new insights into the nitrogen cycle in forest ecosystems. One of those studies[3] found evidence of significant nitrification in tree canopies by analysing the natural Δ17O isotope tracer in precipitation and throughfall collected in beech and pine stands across a nitrogen deposition gradient in 10 ICP Forests Level II plots. Additional genetic analyses of leaf samples allowed the identification of archaea and specialized bacteria as the main taxa controlling this process. The results suggest that the contribution of reduced nitrogen (NH4+) to total deposition, and thus its impact on forest ecosystems, is likely to be underestimated. The results are also relevant for the debate on the widespread nitrogen saturation of ecosystems compared to oligotrophication and can be used

[3] Rossella Guerrieri and others, “Substantial contribution of tree canopy nitrifiers to nitrogen fluxes in European forests”, *Nature Geoscience*, vol. 17 (2024), pp. 130–136.

to improve canopy budget models. One study[4] investigated the effects of tree pollen on element fluxes in the throughfall during spring in homogeneous beech, oak, spruce and pine stands. Use was made of throughfall measurements of deposition at the ICP Forests Level II sites and seasonal pollen integrals from aerobiological monitoring stations at nearby sites. For beech in particular, a positive correlation was found between airborne pollen concentrations and fluxes of potassium, ammonium, organic nitrogen and carbon in the throughfall. On the other hand, the results indicated that pollen or associated microorganisms can reduce the amount of nitrate in precipitation.

B. Catchment areas and light open nature

12. Biodiversity: Preliminary results from a study[5] tracking ground vegetation community stability and resilience over time show that most Integrated Monitoring sites are (as expected for unmanaged seminatural forests) largely stable over the monitoring period. Natural disturbances such as bark beetle attacks are clearly seen in the results as a major challenge to resilience (confirming the method), but the more subtle effects of nitrogen and sulfur deposition on vegetation communities are still under investigation at the time of writing, with final results expected later in 2024. However, even if site-specific trends are subtle, vegetation data from Integrated Monitoring have previously proven to be very valuable in larger scale studies covering Europe-wide gradients when assessing effects on vegetation by air pollution.[6]

13. Given the renewed focus on biodiversity work under the Convention on Long-range Transboundary Air Pollution (Air Convention), a dynamic modelling study[7] was undertaken at the Swedish Integrated Monitoring sites. The focus was on the predictive ability of the models for vegetation composition. While generally acceptable levels of alignment between predicted probability of plant species occurrence and observed occurrences were found, model performance was notably stronger for vascular plants than for mosses. This is a reflection of the Central/Western European-dominated training data for the model, and adding data from boreal forests where non-vascular parts of the vegetation are more important would improve model performance in these areas.

C. Air pollution effects on surface waters

14. Critical loads for acidification of surface waters are still exceeded in some places. This is particularly evident in southern Norway and western parts of the Netherlands, but exceedances are observed in all countries that report these critical loads. Both the level and extension of exceedance have declined strongly since the 1980s. This is mostly related to the declines in emissions of sulfur, since sulfur contributes most to surface water acidification from air pollution. Non-exceedance does not, however, imply full protection of aquatic biological communities and biodiversity, due to lag times in both chemical and biological recovery.

15. A recent assessment of diversity of aquatic macroinvertebrates shows increases in diversity of sensitive groups (Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa: mayflies, stoneflies and caddisflies) in 47 per cent of rivers and 35 per cent of lakes with sufficient length of monitoring records. Thus, there is a gradual return of sensitive taxa, which is consistent with chemical recovery. However, in the most acid-sensitive areas, surface waters remain below critical limits for biological recovery and changes in diversity of sensitive groups have stalled. Further reductions in sulfur and nitrogen emissions will benefit

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[4] Arne Verstraeten and others, “Effects of tree pollen on throughfall element fluxes in European forests”, *Biogeochemistry*, vol. 165 (2023), pp. 311–325.

[5] James Weldon and others, “Forest vegetation community stability affected by airborne pollutants”, forthcoming.

[6] Thomas Dirnböck and others, "Forest floor vegetation response to nitrogen deposition in Europe", *Global Change Biology*, vol. 20, No. 2 (February 2014), pp. 429–440.

[7] James Weldon, “Modelling forest biodiversity and recovery from acidification”, Report 2024:2 (Uppsala, Department of Aquatic Sciences and Assessment of the Swedish University of Agricultural Sciences, 2024).

chemical and biological recovery of acid-sensitive surface waters. It is important to include critical loads for acidification in the Gothenburg Protocol revision process because critical loads for nitrogen alone are not sufficient to protect aquatic biodiversity and ecosystem functioning.

D. Biodiversity

16. Air pollution as a pressure on biodiversity has been an important topic for many years. It is included in the work programme of the Working Group on Effects, as well as those of the most of the international cooperative programmes. While scientific progress has been made and reported for different ecosystem types and species, it has been more difficult to find an approach that allows air pollution as a pressure on biodiversity to be included in the integrated assessment modelling.

17. In recent years, the Working Group on Effects, in cooperation with the Task Force on Integrated Assessment Modelling (TFIAM) and CIAM, has developed an approach for regional assessment that can be integrated into IAM and be ready for use for the Gothenburg Protocol revision. The approach has the same basis as the European Union nature policies such as the Habitats Directive[8] and nature policies in many countries: that biodiversity is protected by protecting habitats and species. For the habitats, the diversity, area and quality need to be protected where air pollution is a pressure on the quality of habitats. For air policies, the area of the different habitat types can be assumed to be protected through the nature policies. Diversity can be protected through protecting a range of different habitat types covering the variation in plant-distributing factors such as nutrient availability, pH, moisture, light openness and salinity. This is the case for the EUNIS nature classification system, which has also been used as a basis for the development of empirical critical loads. An update of a European receptor map and empirical critical loads has been carried out recently by the Coordination Centre for Effects (CCE) (see paras. 19–23).

18. While the aim will be to have zero exceedance for all nature types, a gap closure might be needed for IAM. Here, the reduction in average accumulated exceedance can be used with the aim of achieving equal improvement for all nature types. This is important because the nature types, as described, are expected to be habitat for different typical species. It will also be important to use harmonized critical loads and receptor maps for the optimization. However, country-scale assessments can be made ex-post, also based on nationally submitted critical loads.

VI. Critical loads and levels

A. Critical loads

19. In 2023, the CCE of the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends (ICP Modelling and Mapping) finalized the updated version of the European receptor map (see report entitled *Final Report: Creation of a Harmonized Land Cover Map as an Example for the Entire Region of the Geneva Air Pollution Convention)*.[9] This database provides a uniform distribution of more than 200 different ecosystem types on EUNIS level 3 across the whole ECE region including the Eastern Europe, the Caucasus and Central Asia countries. The map can be provided to national focal centres for their national purposes upon request to CCE. Also, it may form a common basis for ecosystem-related modelling of dispersion and deposition of air pollution and related risk assessment with indicators such as critical loads and levels.

[8] Available at https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en.

[9] Steffen Gebhardt, Report No. 157/2023 (Dessau-Roßlau, German Environment Agency, 2023).

20. Following the recent update of empirical Critical Loads for nitrogen (see report *Review and revision of empirical Critical Loads of nitrogen for Europe*),[10] in 2023, CCE provided a stable ECE-wide approach to attribute these data to EUNIS ecosystems. The resulting map was elaborated by interlinking empirical Critical Loads for more than 50 different ecosystems with the updated receptor map (see report cited above).

21. With a call for data in 2023, National Focal Centres of the ICP Modelling and Mapping were asked to apply the updated Empirical Critical Loads to their national territories and thus produce a national basis for future risk assessments. Following that call for data, CCE gathered updated national data sets from 11 countries. The maps resulting from the call for data reflect national knowledge on ecosystem distribution and national preferences for the protection level. The national deliveries will be included in the ECE-wide policy relevant data set of Critical Loads for nitrogen.

22. The current ECE-wide data set of empirical Critical Loads is expected to reflect risks for biodiversity through air pollution in a relevant way. This is because the exceedance of empirical Critical Loads in many cases is associated with observed shifts in species abundance and reduction or disappearance of indicator species.

23. The *Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends*[11] was updated by CCE in 2023, with updates of chapters 3, on critical levels for ammonia, and 5, on the background database for critical load modelling and the ECE receptor map.

B. Critical levels: Effects of air pollution on vegetation and crops

24. Critical levels for ammonia. In 2023, CCE finalized the review and revision of Critical Levels for ammonia following a literature review and the organization of a workshop.[12] In summary, the existing concentration levels to protect vegetation from harmful ammonia concentration were confirmed. As a follow-up to this activity, CCE presented an approach of linking the updated levels with the new receptor map, to provide a basis for future risk assessment. The resulting ECE-wide database was deemed relevant for inclusion in the revision of the Gothenburg Protocol. With the help of interested national focal centres, this activity will be finalized by early 2025 and the data will be delivered to CIAM for optimization calculations.

25. Ozone impacts on crop senescence: the start of senescence is a key growth stage for ozone impacts on wheat, as this affects the grain fill, with a reduced grain fill causing a reduction in yield due to reduced grain size (but not reduced grain number). Recent development of a nitrogen module within the Deposition of Ozone for Stomatal Exchange (DO3SE) model will allow an assessment of ozone impacts on crop quality (in terms of protein content of grains) for wheat. Accelerated onset of senescence was shown from the model outputs to be the key process affecting grain nitrogen (and subsequently protein).

26. Yield reduction in tropical crops: while the negative impacts of ozone on the yield of widespread crops such as wheat, rice and common bean are well-established, current research involves investigating how ozone pollution affects the yield of important tropical crops. Scientists in Brazil, Italy and the United Kingdom of Great Britain and Northern Ireland have developed a flux-effect relationship for sugarcane and applied this to the main sugarcane production areas of Brazil. This demonstrated that 5.6–18.3 per cent of total sugarcane crop productivity is lost across the region due to ozone exposure.

27. Floral signalling: ozone (and nitrogen dioxide) pollution has the potential to disrupt grassland habitats via impacts on pollinators, which are vital components of a healthy

[10] Roland Bobbink, Christin Loran and Hilde Tomassen, eds., Report No. 110/2022 (Dessau-Roßlau, German Environment Agency, 2022).

[11] United Nations Economic Commission for Europe (ECE) Convention on Long-range Transboundary Air Pollution, Report No. 109/2023 (Dessau-Roßlau, German Environment Agency, 2022).

[12] Available at https://www.umweltbundesamt.de/en/publikationen/review-of-internationally-proposed-critical-levels.

ecosystem. These pollutants disrupt the floral signal, likely affecting the ability of pollinators to detect flowers. Increased ozone levels also lead to reduced flower numbers in sensitive species, having further impact on pollinators in important grassland habitats.

28. Airborne microplastics: mosses can be used as a biomonitor for airborne deposition of microplastics. Data from the MADAME project have shown that airborne microplastics are found throughout the ECE region, even in rural areas such as Scandinavia and western Ireland. A wide range of microplastics have been found in moss samples, including from textiles and plastic litter. The types of polymer include polyurethane, cellulose acetate and polyethylene. Future research required includes investigations on microplastic retention time in moss, whether microplastics are internal to the moss tissue or remain external, and possible impacts on vegetation and the wider ecosystem.

C. Temporal development of air pollution effects

29. Water chemical records of over 500 acid-sensitive lakes and rivers in 10 regions in Europe and North America display significant declines in sulfate in almost 100 per cent of all sites. In all, 4 out of 10 regions also show significant declines in nitrate. All sites show strong increases in acid-neutralizing capacity, but a less prominent increase in pH. The lower increase in pH is related to increases in organic acidity, a consequence of higher organic matter solubility under lower sulfate deposition. Changes in sulfate, acid-neutralizing capacity and pH indicate that chemical recovery has slowed in Europe while accelerating in North America since the early 2000s. This is related to slower emission declines of sulfur in Europe and faster declines of sulfur in North America after the 2000s.

30. In less acidified sites with a pH over 5.5, an increase in calcium has been observed despite the decline in strong acid anions (e.g., sulfate, nitrate and chloride). The decline in calcium is associated with an increase in bicarbonates, which could be related to increased weathering rates. Thus, in some lesser acidified sites of lower acid-sensitivity, chemical recovery may be quicker than expected.

31. Ongoing dynamic modelling of chemical recovery of acid-sensitive lakes in southern Norway will increase understanding of recovery processes in the most acid-sensitive surface waters elsewhere in Europe and North America. The results will inform the Gothenburg Protocol revision process.

32. Over the past year, air quality research and monitoring activities outside the ICP Forests community have focused on determining trends in pollutants, particularly ozone and its precursors, using models with in-situ and remote sensing data as input. One study[13] also found that ozone trends are increasing not only due to its “traditional precursors”, but also due to increased photolysis of nitrate particles. Taking climate change and air pollution into account, statistical downscaling predicts a decrease in ground-level ozone concentrations in the European region under the moderate SSP2-4.5 scenario, but an increase in concentrations under the pessimistic SSP3-7.0 scenario.[14] Therefore, the effects of ozone on vegetation could become increasingly noticeable. In this context, one study[15] showed that summertime ozone concentrations and foliar symptoms in European forests decreased slightly in 2005–2018. Ozone concentrations were higher in the Mediterranean and Alpine biogeographical regions. Ozone has a significant effect on symptoms in the most sensitive species. It was also shown that symptoms tend to be determined by functional leaf properties.

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[13] Viral Shah and others, “Particulate nitrate photolysis as a possible driver of rising tropospheric ozone”, *Geophysical Research Letters*, vol. 51, No. 5 (March 2024).

[14] Elke Hertig, Sally Jahn, and Irena Kaspar-Ott, “Future local ground-level ozone in the European area from statistical downscaling projections considering climate and emission changes”, *Earth’s Future*, vol. 11, No. 2 (January 2023).

[15] Marco Ferretti and others, “The fingerprint of tropospheric ozone on broadleaved forest vegetation in Europe”, *Ecological Indicator*, vol. 158 (January 2024).

VII. Emissions

A. Improving emission inventories

1. General issues

33. In 2024, all but two of the Parties to the Air Convention had provided air emission inventories. This represents the highest score achieved since the inception of the reporting process.

2. Gridded emissions used for modelling

34. Reported spatial emission data (gridded emission data) are input to models used to assess atmospheric concentrations and deposition, as the spatial location of emissions largely determines their atmospheric dispersion patterns and impact area. The Centre on Emission Inventories and Projections (CEIP) has prepared gridded data of main pollutants (nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), ammonia (NH_3), sulfur oxides (SO_x), carbon monoxide (CO), particulate matter ($PM_{2.5}$, PM_{10}, coarse PM) and black carbon for the time series 2000–2022. Gridded data for heavy metals (HMs) (cadmium (Cd), mercury (Hg) and lead (Pb)) and persistent organic pollutants (POPs) (benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, dioxins and furans, hexachlorobenzene) were prepared for the year 2022.

35. In order to compile the gridded data sets, the CEIP took stock of numerous data sources, in addition to national emissions. These included data from the Greenhouse Gas – Air pollution Interactions and Synergies model (GAINS), shipping emission data gathered by the Finnish Meteorological Institute and data from the Emissions Database for Global Atmospheric Research v6.1[16] built up by the European Commission Joint Research Centre. Despite the semi-automatic gap-filling system developed by CEIP, the gap-filling work still requires high levels of resources. There are still several Parties that do not report gridded data and there are also quality issues with reported gridded data. Furthermore, there is often a lack of transparency in the documentation of the methodologies used to prepare the gridded data. It is essential that Parties, EMEP centres and task forces work together to enhance the quality of the gridded data set.

3. Synthesis of current reporting of the condensable part in particulate matter

36. Particulate matter can exist as solid or liquid matter (the “filterable” portion) or as gases (the “condensable” portion). The inclusion of the condensable component of PM emissions can have a big impact on the emission estimate for certain sources. In 2024, 23 Parties provided information on the inclusion of the condensable component in the emission factors for PM emissions. At the level of the total inventory, a combination of emissions including and excluding the condensable component is typically reported. Furthermore, for several sources (industries, aviation), it is unclear to what extent condensables are included in the emission estimates. With regard to residential heating – which represents a significant source of PM emissions – there has been a notable increase in transparency of reporting. In recent years, an increasing number of countries have included the condensable component in their PM emission estimates for residential heating. Nevertheless, more than a third of the reported air emission data for the residential heating sector still require replacement by alternative emission estimates before they can be used for modelling purposes.

4. In-depth review

37. In 2023, the in-depth review of air emission inventories submitted under the Air Convention focused on emissions from agriculture, with a special emphasis on NH_3, NMVOC and NO_x emissions, including gridded data for the sector agriculture. All 41 Parties that had provided air emission data prior to the commencement of the review were reviewed. In general, the quality of air emission reporting has improved in recent years. Nevertheless,

[16] See https://edgar.jrc.ec.europa.eu/overview.php?v=431.

considerable discrepancies remain between the quality of air emission reporting among Parties. The review reports are accessible on the CEIP website.[17]

B. Applications for adjustments to emission inventories

38. Two new and four previously approved adjustment applications have been assessed by the Expert Review Team in 2024 and have been imported into the website tool, where all information can easily be viewed and compared.[18] Recommendations to the EMEP Steering Body are provided in the report on review of adjustment applications (ECE/EB.AIR/GE.1−WG.1/2024/INF.6).

VIII. Monitoring and modelling

A. Lessons learned from the last Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe field campaign of summer 2022

39. The EMEP Chemical Coordinating Centre (CCC), on behalf of the Task Force on Measurements and Modelling (TFMM), coordinated an intensive measurement period from 12 to 19 July 2022, which coincided with a pan-European heatwave. The field campaign included 28 sites in 13 countries, measuring more than 140 different volatile organic compounds (VOCs) species, in addition to measurements of ozone, nitrogen oxides, elemental carbon and organic carbon (EC/OC), and more than 40 different organic tracers for secondary organic aerosols (SOAs). The overall results showed that oxygenated VOCs (OVOCs) are dominant together with C2–C5 non-methane hydrocarbons (NMHC) at EMEP sites, suggesting a strong need for more regular measurements of OVOCs by the Parties. There is also a need for more measurements of biogenic VOCs, such as monoterpenes, which are important sources of SOAs. Furthermore, the high-resolution measurements have proven very useful in assessing model evaluation of the temporal variations and emissions of VOCs.

40. During 2023, the Meteorological Synthesizing Centre-West (MSC-W) conducted the first extensive comparison of modelled versus observed VOC species, both for long-term EMEP measurements and also for the 2022 intensive campaign. Results were mixed, suggesting an issue with VOC emission inventories, although model performance for the key photo-oxidant precursor and product formaldehyde (HCHO) was satisfactory, suggesting that the model is effectively capturing the overall photo-oxidation chemistry processes.

B. Update and evaluation of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe model

41. The new source apportionment method in the EMEP MSC-W model, "Local Fractions", has been extended to include all the species in the chemical mechanisms, and can now account for the non-linear terms. The major advantage of this new method is that it is very central processing unit-efficient and can thus be used for analysing source apportionment and chemical regimes in much more detail. Such detailed analysis is being done for O_3, and the results will be used to determine the input and parametrization for an updated version of GAINS for simulating O_3 response to precursors' emission reductions. The photolysis rate calculations in the EMEP model, critical to photochemical O_3 formation, have also been updated and evaluated based on the Cloud-J scheme. Secondary inorganic PM partitioning between the gas and particle phase has also been updated to be calculated using the most recent ISORROPIA-Lite scheme.

[17] Available at www.ceip.at/status-of-reporting-and-review-results/2023-submission.
[18] Available at www.ceip.at/gothenburg-protocol/adjustment-tool.

42. Work has commenced on an update of both the soil NO emissions and the biogenic VOC emissions in the EMEP model. MSC-W has started to compare soil NO and HCHO calculations used in EMEP with satellite data from the TROPOspheric Monitoring Instrument (TROPOMI). The results suggest possible underprediction of soil NO from forests in Spain, but the reasons for this are unclear.

43. EMEP simulations of global NO_2 concentrations were sampled at TROPOMI overpasses to evaluate at which locations the emission of NO_x from soil might be dominant in the TROPOMI tropospheric NO_2 retrievals. As expected, the highest contributions of soil-emitted NO_x to the tropospheric NO_2 column are found in the Sahel region, where in spring about 50 per cent of the column originates from soil emissions according to the simulations. Different emission parameterizations have been compared to see which of them has the best match with the observations.

C. Integrated assessment modelling

44. Preliminary modelling results were produced in the context of workplan item 2.1.12, the informal document “Policy brief on the potential implications of introducing collective risk-based targets for the ECE region to address air pollution impacts on health and ecosystems”. A first version was presented at the forty-third meeting of the Executive Body (Geneva, 11–14 December 2023). A revised version was submitted to the sixty-second Working Group on Strategies and Review session (Geneva, 27–31 May 2024), incorporating replies to comments received from Parties. It describes policy scenarios up to 2050 calculated with GAINS for the ECE region: a baseline (current legislation – CLE), a maximum technically feasible reductions (MTFR) scenario, and an alternative “LOW” scenario, including climate policies compatible with the 2°C Paris Agreement goal for the whole world, MTFR measures (also for maritime shipping), and further transformational changes in agriculture. Key findings are the following:

(a) Reaching a 50 per cent reduction in regionwide PM health effects appears feasible, although the target cannot be met by all Parties. Regionwide targets are more cost effective than country-specific targets. Dietary changes and climate change policies will further facilitate achievement of targets. For the European Union, the target is achieved in the baseline scenario. Here, implementation is crucial. Some non-European Union countries may struggle to achieve the target, especially when accounting for population growth and ageing. A target defined using static population or mortality risks per 100,000 inhabitants seems achievable with less additional effort;

(b) Health targets are more difficult to achieve for ozone, due to the current global increase in methane emissions partly offsetting reductions in European precursor emissions in the baseline scenario up to 2050. Further ozone reductions would be feasible by 2050 under the LOW scenario, with approximately one third of these reductions attributed to the reduction in global methane emissions, one third to the reduction in European non-methane precursor emissions and one third to the reduction in non-methane precursor emissions outside Europe;

(c) Empirical critical loads for nitrogen from CCE were introduced into the GAINS model to assess the feasibility of a 50 per cent reduction in average accumulated exceedance per nature type; a metric suggested as a proxy for air pollution pressure on biodiversity by the Working Group on Effects. The attainability differs amongst countries and ecosystem types and depends on whether the higher or lower critical load values are used. When using the lower critical loads, the target cannot be met in Eastern Europe, the Caucasus and Central Asia and Türkiye, where a large increase in fertilizer use is included in the baseline. Further analysis will focus on achievement of lower and mean (average) critical load values. Additional efforts would also be needed to reach a 50 per cent reduction for forests and semi-natural ecosystems;

(d) First analyses of flexibilities aimed at facilitating ratification of a future revised Gothenburg Protocol for current non-Parties (Western Balkans, Eastern Europe, the Caucasus and Central Asia and Türkiye) show again that a given target can be reached at lower cost when it is to be attained by the overall region, than when it is to be reached by each country. Cost-effectiveness would be lower if these countries implemented the current best available techniques for a selection of sectors (power plants, industry, transport), compared to implementing measures chosen in the GAINS optimization for the common target of a 50 per cent reduction in health effects.

45. The GAINS scenarios will be updated during 2024. Following ongoing bilateral consultations with Parties, the new baseline scenario is expected in June 2024.

46. Further guidance from the Working Group on Strategies and Review is needed, amongst other things, on: the target and base year for target optimization; whether or not to include demographic change in the modelling; whether to consider the absolute number of deaths or deaths per 100,000 inhabitants; whether or not to include natural PM; and whether to apply the target to the ECE region or to each country.

47. The GAINS modelling benefits extensively from collaboration with the other expert groups of the Convention. Notably, since last year, collaboration with MSC-W and the Working Group on Effects/CCE has enabled improved analysis of ozone and biodiversity effects with the GAINS model.

48. At its fifty-third meeting (Paris, 15–17 April 2024), TFIAM discussed a draft of the “Guidance document on non-technical and structural measures” (workplan item 2.2.3), for which an annotated outline was submitted to the sixty-second Working Group on Strategies and Review session. Applying such measures may reduce health and environmental impacts from air pollution further and at relatively lower costs than technical end-of-pipe technologies. However, their implementation is more difficult, requiring the use of various policy instruments, and they depend on specific situations in the countries. Subsequently, results from one implementation example may not apply everywhere across the studied region, and the costs and benefits of such measures are more difficult to assess than those of technical measures.

D. Other items relevant to measurement and modelling

49. Activities within the scope of TFMM for 2023–2024 confirmed that an accurate representation of VOC emissions and their chemical transformations in models is essential in the context of ozone and secondary aerosol formation. Biogenic VOCs are a very important precursor to ozone, especially during heatwave episodes, where their impact may reach up to 40 per cent. Additionally, VOCs contribute to the generation of SOAs through various oxidation processes. The challenge in modelling VOCs lies in the diversity and variability of their sources, both natural and anthropogenic, as well as their reactivity to and interaction with other atmospheric constituents. For European countries, changes in VOCs monitoring related to the implementation of the revised European Union Ambient Air Quality Directives[19] contribute in the long term to better understanding of their concentration variability.

50. Several analyses undertaken by TFMM experts confirm the observed decreasing trends, reproduced by model simulations for most primary pollutants. This trend is partly related to the implementation of environmental policies, but changing meteorological conditions, especially during winter, also play an important role. However, in the case of ozone, the background concentrations have slightly increased, which justifies further work on this topic.

51. A workshop on chemicals of emerging concern was held at EMEP CCC (Kjeller, Norway, 8–10 November 2023) with the aim of harmonizing atmospheric monitoring of these species, in cooperation with the Arctic Monitoring and Assessment Programme and the Global Monitoring Programme under the Stockholm Convention on Persistent Organic Pollutants. There were thematic sessions on siloxane, chloro-paraffins, per- and polyfluorinated substances, flame retardants, microplastics and plastic additives. A general recommendation was to conduct measurement campaigns to gain a better insight into their spatial variability, as well as comparing the different methods used. Furthermore, it was

[19] Available at https://environment.ec.europa.eu/topics/air/air-quality_en.

concluded that it is important that more of these observations be reported to EMEP and that, in order to facilitate that reporting, guidelines need to be developed.

IX. Linking the scales

A. Hemispheric transport of air pollution

52. Under the current workplan 2024–2025, the Task Force on Hemispheric Transport of Air Pollution (TFHTAP) has focused on planning and launching updates to global emissions data sets and three global atmospheric modelling intercomparison studies that will help inform revision of the Gothenburg Protocol and future reviews of the Protocol on Heavy Metals and the Stockholm Protocol, as well as the first effectiveness evaluation of the Minamata Convention on Mercury.

53. With respect to global emissions, TFHTAP is working to extend the 2000–2018 time series of global emissions for O_3 precursors and PM components and precursors that was released in 2022. The update will extend the time series to 2020, incorporate new global information from Emissions Database for Global Atmospheric Research version 8, incorporate regional information from the Multi-resolution Emission Inventory for China, and improve the sector-specific comparability of some of the constituent regional emissions data sets. TFHTAP hopes to complete this extension by late 2024.

54. The first of the three global model intercomparison studies is the Multi-Compartment Mercury Modelling and Analysis Project (HTAP3/MCHgMAP). MCHgMAP is linking global atmospheric, land, oceanic and multi-media models to account for contemporary and historical changes in mercury cycling in the environment. The study is designed to inform the review of the Protocol on Heavy Metals and the first effectiveness evaluation of the Minamata Convention. A paper describing the study design has been submitted for publication and the modelling work is underway. The first phase of MCHgMAP will be completed in 2024 and 2025 to contribute to the Minamata Convention, and a second phase will be conducted in 2026 and 2027 to contribute additional policy-relevant information to inform the review of the Protocol on Heavy Metals.

55. The second global model intercomparison is known as the Ozone, Particles, Nitrogen and Sulfur study (HTAP3/OPNS). OPNS includes three types of modelling experiments: simulating future policy scenarios to 2050, deriving global source-receptor relationships under a 2050 emissions scenario, and simulating historical emission trends for 2003–2020. Future emission scenarios are being developed by CIAM. The experiments are designed to address science questions relevant to the revision of the Gothenburg Protocol, including understanding the impact of local and global methane emission decreases on ozone impacts in the ECE region. The experiments are expected to get underway mid-2024 and have initial results as soon as spring 2025.

56. The third global model intercomparison, known as HTAP3/Fires, is focused on the multi-pollutant impacts of wildfires and agricultural burning. Fires produce emissions of a wide variety of pollutants, including fine particles and their precursors, ozone precursors, toxic metals and POPs. Fires have impacts on health, ecosystems and climate change. HTAP3/Fires is intended to bring a variety of different types of models together to understand the multi-pollutant impacts of fires, how they have changed over time, and how they are expected to change in the future. The experiments are expected to get underway in late 2024 and be completed in 2025 and 2026. The results will help inform future reviews of the Gothenburg Protocol, the Protocol on Heavy Metals and the Stockholm Protocol.

B. City scale

57. In 2023, ICP Materials carried out a study where application of models with increased resolution was performed at selected UNESCO sites in Switzerland. Corrosion values calculated using national (Swiss) models with resolutions ranging from 100 m to 1,000 m were about 20 per cent higher compared to values calculated using the EMEP01 model.

58. At the fifty-third TFIAM meeting (Paris, 15–17 April 2024), the outline of the Expert Panel on Clean Air in Cities paper "Position on clean air in cities" (workplan item 2.1.4), was discussed. The paper will be submitted to the sixty-second session of the Working Group on Strategies and Review. The document will deal with management options for city air quality, including possible win-win solutions with climate policies, the importance of transboundary and trans-city transport of pollution, and examples of the importance of local, national and regional measures.

X. Methane

59. A large body of work from within and outside the Air Convention over the past two decades has shown the importance of methane as an ozone precursor. This work is difficult to synthesize due to the use of different emission scenarios, modelling approaches, base and target years and impact metrics. Despite these difficulties, some key conclusions can be drawn. A recent synthesis of work conducted by TFHTAP, TFMM, MSC-W, CIAM and the Joint Research Centre of the European Commission has identified some common messages.

60. Under the baseline (CLE) scenario, peak season MDA8 in the EMEP region is projected to reduce by 5–10 per cent between 2015 and 2050. A continuing increase in ozone attributable to rising global methane emissions partially offsets the reductions in ozone expected from reductions in emissions of NO_x and NMVOC. Under the LOW scenario, which includes all technically feasible reductions in NO_x, NMVOC and methane globally, as well as additional non-technical measures, European peak season ozone in 2050 is projected to be reduced by a further 20 per cent compared with 2050 CLE. Approximately one third of this reduction is due to reductions in European NO_x and NMVOC, another third is due to non-European NO_x and NMVOC, and the remaining third is due to global methane reductions. Despite this, the projected peak season MDA8 in 2050 under the LOW scenario will still not meet the WHO air quality guideline level.

61. CIAM estimates that methane emissions can be reduced in the ECE region by almost 70 per cent between 2015 and 2050 under the LOW scenario, when dietary change and livestock reductions are included in addition to technical measures.

XI. Reorganization and relocation of Meteorological Synthesizing Centre-East activities

62. Following the decision of the Executive Body of the Convention at its forty-third session (Geneva, 11–14 December 2023),[20] the activities of EMEP Meteorological Synthesizing Centre-East (MSC-E) on model assessment of heavy metal and POP transboundary pollution have been hosted by the Jožef Stefan Institute (Ljubljana) since 1 January 2024. MSC-E has commenced implementing operational activities in accordance with its Revised mandate (ECE/EB.AIR/144/Add.1, decision 2019/11) and the 2024–2025 workplan for the implementation of the Convention (ECE/EB.AIR/154/Add.1), performing capacity-building of the Centre, engaging research staff, and arranging necessary computer and software resources.

63. Starting from the beginning of 2024, the scientific staff of MSC-E have successfully undertaken preparations for the annual operational modelling and conducted pilot simulations of selected heavy metals and POPs. Research activities of the Centre have involved updates and improvement of the GLEMOS chemical transport model, as well as collaboration with TFHTAP on its multi-compartment mercury modelling and analysis project (MCHgMAP). MSC-E has also initiated a country-scale pilot study of selected POPs and heavy metals pollution in the Balkan countries. Progress and preliminary results of the Centre's activities were reported at the twenty-fifth annual meeting of TFMM (Warsaw, 6–7 May 2024).

[20] ECE/EB.AIR/154, annex I, decision 2023/1, para. 1.

XII. Open data policy and communication actions

64. ICP Integrated Monitoring is in the process of moving from the traditional "by request" model of data provision to open data publication according to the FAIR principles (Findable, Accessible, Interoperable and Reusable). Participating countries were asked to formally consent to publish data under a Creative Commons by-attribution licence at the thirty-second Task Force meeting (Prague, 28–30 May 2024). Subsequently, the Programme Centre will make the database available online, and a data paper describing the monitoring programme and the available data will be published to facilitate attribution and provide citations when the data are used. This process is expected to be completed in 2024–2025.

65. All ICPs under the Working Group on Effects have been requested to develop a clear timeline on giving open access to data, explaining what will be available and when, and to present those plans and timeline at the tenth joint session of the EMEP Steering Group and the Working Group on Effects.