United Nations ECE/EB.AIR/2022/10

Economic and Social Council

Distr.: General
29 September 2022

Original: English

Economic Commission for Europe

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

Forty-second session
Geneva, 12–16 December 2022
Item 4 (a) of the provisional agenda
Review of the implementation of the 2022–2023 workplan: science

Strategy for scientific bodies under the Convention on Long-range Transboundary Air Pollution

Document 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 members of the extended bureaux of both subsidiary bodies

Summary

The Strategy was 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 members of the Extended Bureaux of the Working Group on Effects[a] and the Extended Bureau of the Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe.[b] The Strategy is a compilation and update to two documents: the Revised long-term strategy of the effects-oriented activities and the Revised strategy for the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe for 2010–2019 – two long-term strategies for the Working Group on Effects and the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, respectively. The document was approved at the eighth joint session 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 (Geneva, 12–16 September 2022). The Executive Body is invited to adopt this Strategy at its forty-second session.

[a] Comprising the Bureau of the Working Group, the chairs of the international cooperative programme task forces, the Joint Task Force on the Health Effects of Air Pollution and representatives of the international cooperative programme centres.
[b] Comprising the Bureau of the Steering Body, the Chairs of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe task forces and representatives of Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe centres.

I. Introduction

1. 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 (WGE) are the scientific and technical subsidiary bodies that provide the United Nations Economic Commission for Europe (ECE) Convention on Long-range Transboundary Air Pollution (Convention) with technical support on how to achieve environmental goals in a cost-effective way.

2. The structure of the Convention, with its policy and science subsidiary bodies, is illustrated by an organizational chart of the instrument contained in the annex to the present document.

3. EMEP was initiated in 1977 as a special programme under ECE. It has operated under the Convention since it entered into force in 1983.

4. The Executive Body for the Convention decided at its seventeenth session (Gothenburg, Sweden, 29 November–3 December 1999) that the main objective of EMEP was: "to provide sound scientific support for the Convention, in particular in the areas of atmospheric monitoring and modelling emission inventories, and emission projections and integrated assessment".[1]

5. EMEP has, during its more than 40 years of existence, taken a leading role at the international level in supporting air pollution policy development and its implementation. It has developed a unique and specific capacity to quantify long-range transport of air pollution, including source-receptor relationships for calculation of transboundary fluxes, as well as a widely accepted system for quality assurance of methods and results in the emissions, measurement and modelling fields.

6. WGE was established under the Convention in 1980 to develop the necessary international cooperation regarding research on and monitoring of pollutant effects. The work is underpinned by scientific research on dose-response, critical loads and levels and assessment of damage to different receptors. Its six international cooperative programmes – the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), the International Cooperative Programme on Assessment and Monitoring of the Effects of Air Pollution on Rivers and Lakes (ICP Waters), the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP Integrated Monitoring), the International Cooperative Programme on Effects on Materials including Historic and Cultural Monuments (ICP Materials), the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) and the International Cooperative Programme on Modelling and Mapping (ICP Modelling and Mapping) – and the Joint Task Force on Health Aspects of Air Pollution (Task Force on Health) identify the most endangered areas, ecosystems and other receptors by considering damage to human health, terrestrial and aquatic ecosystems and materials.

7. The Convention uses these science-based bodies to support the identification and design of policy responses. Through extended peer review of methods and technical results, EMEP and WGE have developed strong links with the scientific community and relevant stakeholders and support the Convention's goals.

8. In 2016, both bodies prepared an assessment report synthesizing current scientific knowledge on transboundary air pollution issues within the ECE region and assessment of the effectiveness of air pollution measures.

9. The 2016 assessment report[2] showed that the Convention had delivered demonstrable improvements in reducing acidification of the environment and the highest peak levels of ozone (O_3) and photochemical smog, persistent organic pollutants (POPs) and heavy metals (HMs) and had begun to reduce particulate matter (PM) and atmospheric levels and

[1] ECE/EB.AIR/68, annex III, decision 1999/2, para. 1.

[2] Rob Mass and Peringe Grennfelt, eds., *Towards Cleaner Air: Scientific Assessment Report* (Oslo, United Nations Economic Commission for Europe (ECE), 2016).

deposition of nitrogen (N). It has proved to be flexible and dynamic in responding to new challenges and problems in the area of transboundary air pollution. Within the Convention, science is given a prominent role, not only in providing information, but also in sustaining the policymaking process.

10. In order to complete their mission, the science bodies of the Convention seek to develop, maintain and implement methods and tools that support the achievement of goals in the following areas:

(a) Science: to establish sound scientific evidence and provide guidance to underpin, develop and evaluate environmental policies;

(b) Partnership: to foster international partnerships to find solutions to environmental problems;

(c) Openness: to encourage the open use of intellectual resources and products;

(d) Sharing: to share information and expertise with research programmes, expert institutions, national and international organizations and environmental agreements;

(e) Integration: to integrate information on emissions, environmental quality, effects and abatement options, and to provide the basis for solutions;

(f) Leadership: to support the Convention in providing leadership in environmental policymaking at the national, pan-European and global levels.

11. The present report is an update of the two 2010–2019 sciences strategies, the Revised long-term strategy of the effects-oriented activities[3] and the Revised strategy for EMEP for 2010–2019,[4] combined into a single document. The two strategies drove EMEP and WGE work over the past decade. The present report sets out a vision for scientific work and priorities for the period 2022‒2030 and beyond and aims at supporting implementation of the long-term strategy of the Convention over the same period (Executive Body decision 2018/5)[5] and at providing the technical and scientific background to support the implementation of the protocols to the Convention.

12. Despite the progress made under the Convention, air pollution in the ECE region still causes significant environmental and health problems and new challenges continue to emerge. The present document is organized thus: section II reviews strengths and weaknesses considering the main science achievements of the Convention over the past 10 years; section III discusses remaining challenges, which are the driving forces of the science strategy and set its priorities, and focuses on how to strengthen linkages between science and policy and collaboration with other policy areas and science goals; and section IV examines partnerships in and outside the Convention.

II. Main science achievements of the Convention over the past 10 years

13. Over the 40 years of the Convention, considerable success has been achieved in solving environmental and health problems, as a result of reduced emission of atmospheric pollutants. Although initially focused on acidification of forest soils, rivers and lakes, the scope of the effects-related work was widened over the years to include eutrophication of ecosystems by N, effects of several air pollutants on human health, materials and cultural

[3] Available at https://unece.org/fileadmin/DAM/env/documents/2012/EB/Informal_document_no_18_Revised_Long-term_Strategy_of_the_effects-oriented_activities_clean_text.pdf.

[4] Available at www.unece.org/fileadmin/DAM/env/documents/2013/air/emep/Informal_document_no_20_Revised_Strategy_for_EMEP_for_2010-2019_clean_text.pdf.

[5] All Executive Body decisions referred to in the present document are available at https://unece.org/decisions.

heritage, damage to forests, crops and semi-natural vegetation by tropospheric O_3 and harmful effects of HMs on ecosystem compartments.

14. WGE, through its scientific work, supports the Convention by providing policy-oriented information on the degree, geographic extent and development over time of the impacts of major air pollutants. This assessment is based on complementary and mutually supportive approaches such as monitoring, modelling and mapping.

15. The EMEP programme focused on the emissions-measurement-atmospheric modelling continuum to develop tools and databases dedicated to assessment of air pollutant concentrations and deposition in the ECE region, including trends and scenario analysis. Integrated assessment modelling activities form the links between science and policy, designing and assessing emission reduction strategies with cost-benefits approaches that reconcile attainment of control objectives in terms of impact of air pollution on health and ecosystems and national emissions ceiling.

16. Over the past 10 years, WGE and EMEP bodies have cooperated more closely, sharing data and methodological approaches to provide more integrated and unique expertise on air pollution and its impacts. This dialogue was stimulated by the organization of joint meetings[6] and mutual participation in science projects. The publication, in 2016, of *Towards Cleaner Air: Scientific Assessment Report*[7] based on trend reports[8] prepared by EMEP and WGE experts, is an excellent illustration of the value-added and the outcomes of this cooperation, which should be developed further in the future.

17. Work to strengthen the scientific tools in the Convention framework has advanced on many fronts in the last 10 years:

(a) Improvement of the emissions reporting and emission review framework to develop a unique and consistent emission database, gathering information from the Parties to the Convention with support for capacity-building in countries of the Eastern Europe, the Caucasus and Central Asia (EECCA) region. The Convention emission database is managed by the Centre on Emission Inventories and Projections (CEIP). Emission inventory activities are borne by the EMEP/European Environment Agency (EEA) emission inventory guidebook (the EMEP/EEA Guidebook), which has become a reference document beyond the ECE region;

(b) Improvement and dissemination of the EMEP chemistry transport models developed by the Meteorological Synthesizing Centre-West (MSC-W) and Meteorological Synthesizing Centre-East (MSC-E), which are currently run at the global and local scales. Updated parametrization of physicochemical processes implemented in those models and increased spatial resolution allowed for significant reduction of modelling uncertainties in air pollutant concentration and deposition simulations. Source codes have been released to facilitate and support dissemination in the Parties. To better account for users' needs in the countries, MSC-W developed a downscaling approach to deal with urban scale issues, in particular for nitrogen dioxide (NO_2) and PM (urban EMEP (uEMEP) model) and MSC-E derived high-resolution country scale assessments for HMs in countries where large discrepancies between emissions, measurements and modelling results were observed;

(c) The EMEP monitoring network has developed according to the monitoring strategy for EMEP for the period 2020–2019 (ECE/EB.AIR/2019/4). It is coordinated by the Chemical Coordinating Centre (CCC) and is run by national laboratories and experts in the countries. It aims to expand the network geographically, especially toward the EECCA region; running high accuracy observations of a large panel of parameters relevant for describing air pollutant levels and the physicochemical processes that drive them;

[6] WGE and EMEP Steering Body extended Bureaux meeting and annual meetings have been organized jointly since 2015.

[7] Maas and Grennfelt.

[8] Augustin Colette and others, *Air pollution trends in the EMEP region between 1990 and 2012*, EMEP/CCC Report No. 1/2016 (Kjeller, Norway, Norwegian Institute for Air Research (NILU), 2016); and Helen a. de Wit, Jean-Paul Hettelingh and Harry Harmens, *Trends in ecosystem and health responses to long-range transported atmospheric pollutants*, ICP Waters Report No. 125/2015 (Norwegian Institute for Water Research (NIVA), 2015).

implementing long-term observations to gather historical data sets and trends; setting up and coordinating intensive observation periods that focus for a few months on various topics (O_3, carbonaceous compounds, condensable) essential to better understanding the atmospheric processes and potential impact of control measures;

(d) The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model developed by the Centre on Integrated Assessment Modelling – which investigates emission control scenarios to assess their impacts on health and ecosystems and design optimized strategies based on cost-effectiveness analysis linked also to cost-benefit analysis run with the Atmospheric Long-range Pollution Health/environment Assessment Model-Riskpoll tool – has been updated and improved in resolution and accuracy and to account for linkages between air quality and climate. Special care was accorded to the evaluation of national and sectoral projections, measures and cost-curve data bases;

(e) Ecosystems monitoring has characterized the state of the environment, trends in impacts in space and time, and the efficiency and effectiveness of air pollution control measures. The existing environmental monitoring network (ICP Forests, ICP Waters, ICP Integrated Monitoring and ICP Vegetation) under the Convention is undoubtedly one of the largest programmes for harmonized environmental monitoring of air pollution effects. It includes many different receptors, intensive monitoring programmes with common protocols and methodologies, a broad spatial coverage all over most regions of Europe and parts of North America and 20–30 years' worth of historical data. For the continued success of the Convention, it is critical that measurements continue in the various ecosystems;

(f) Modelling ecosystem response and impacts on materials to deposition based on site-specific characteristics allows estimation of the critical environmental deposition threshold below which significant harmful effects do not occur according to present knowledge and is, hence, the basis for critical load calculations. In addition, mapping exceedances of critical loads and levels identifies the geographic distribution and long-term trends of materials and ecosystems risks to air pollution;

(g) The calculation of critical loads and critical levels has been improved for acidification, eutrophication and O_3, and they have been used for impact assessment supporting the development and revision of the Gothenburg Protocol. Critical loads and levels and their exceedances remain as an operational tool to help in setting national emission reduction requirements to protect nature.

18. More details about achievements in each science area investigated by the Convention work are presented and discussed below.

A. Emissions

19. Setting up a robust scientific framework to support emissions inventory activities and emission reporting is one of the most important achievements of the EMEP programme, making the link between science and policy, since emissions inventories are essential as inputs for modelling activities and to assess compliance with obligations of the protocols of the Convention in terms of emission ceilings.

20. The EMEP/EEA Guidebook is the pillar of this activity, providing comprehensive guidance on making emission estimates of air quality pollutants. The technical scope of the Guidebook remains focused on including methodologies for pollutants included in Convention reporting commitments, and the sources that are relevant to the countries within the Convention's geographical extent. The Guidebook is recognized worldwide as a key reference manual for supporting air quality pollutant emission inventories. The Guidebook has also been translated into Russian to improve accessibility for inventory compilers in the ECE region.

21. The methodologies included in the Guidebook are aligned, to the extent possible, with other international conventions, and in particular the guidance on estimating greenhouse gas emissions of the United Nations Framework Convention on Climate Change (UNFCCC), and methodologies published by the United States Environmental Protection Agency. There is ongoing collaboration with UNFCCC in order to maintain consistency in methodologies and

share best science. Black carbon (BC) and, more generally, the topic of short-lived climate pollutants, constitute an example of recent cooperation.

22. To facilitate consistent air emission reporting, the emission reporting guidelines were updated in 2009 and 2014.[9] The main objectives of these guidelines are to: assist Parties in meeting their reporting obligations; support the evaluation of emission-reduction strategies; and facilitate the technical review of air pollutant emission inventories.

23. The number of Parties reporting air emission data increased from 38 to 48 between 2008 and 2021. In addition, the share of Parties that provide an informative inventory report increased from around 70 per cent to 90 per cent between 2008 and 2021.[10] Generally, the air emission data submitted by the Parties has substantially improved over the years in terms of completeness, consistency and timeliness. Last but not least, since 2017, Parties have been obliged, every four years, to report for the year x-2 updated aggregated sectoral gridded emissions in a high-resolution grid of 0.1 x 0.1 degrees and Large Point Sources emissions. This requirement deals with the modelling community’s needs, with spatial distribution of emissions being a key parameter.

24. The annual in-depth review of inventory submissions identifies issues with accuracy, transparency and consistency. As reporting from Parties improves, it becomes possible, as part of the review process, to investigate new issues in detail, and to identify future challenges for the continuous improvement of the emissions reporting system.

B. Monitoring

25. The EMEP monitoring strategy (ECE/EB.AIR/2019/4) specifies the detailed requirements for monitoring air pollutant concentrations and deposition in the Parties. Formally established in 2000, it is updated every 10 years. The latest revision fixes objectives for the period 2020–2029. The EMEP monitoring strategy is the core European framework for regional-scale monitoring of atmospheric constituents, and the observations are broadly used to assess exposure and impacts on health, ecosystems, vegetation, materials and climate. This includes evaluation and assessment of regional and transboundary contributions to local air pollution, as well as understanding the role of intercontinental and global scale transport of short- and long-lived species.

26. The spatial coverage of sites has improved for several components, especially for measurements of aerosol properties, though there still is insufficient coverage in some areas, in particular in the EECCA region. The quality of the EMEP observations is well documented, and harmonization of guidelines, observational practices and data quality control procedures are developed in close cooperation with several networks and infrastructures (i.e. Global Atmosphere Watch, the Aerosol, Clouds, Trace gases Research Infrastructure (ACTRIS)). Even though the measurement programme and procedures are conservative in order to ensure comparability from a long-term perspective, the programme is also dynamic and utilizes new developments in observational methods and techniques. These can be tested during intensive observation periods conducted every 2–4 years that are now essential components of the monitoring strategy.

27. Complexity and robustness in data flow and dissemination have increased and include protocols for the Findability, Accessibility, Interoperability and Reuse (FAIR) principles, and the new EBAS[11] database infrastructure where EMEP monitoring data are stored, is closely linked to international developments related to harmonization of metadata standards. EBAS benefits from long-term commitments of several national and international monitoring programmes and/or research infrastructures, in addition to EMEP, making it sustainable and versatile. The data centre activities are closely linked to research and quality assurance

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[9] Current version ECE/EB.AIR.125.

[10] Katarina Mareckova and others, *Inventory Review 2021: Review of emission data reported under the LRTAP Convention – Stage 1 and 2 review – Status of gridded and LPS data*, CEIP Technical Report No. 03/2021 (Vienna, The Environment Agency Austria, 2021).

[11] See https://ebas.nilu.no/.

activities and there is a strong link to user communities' needs that makes EMEP more visible.

C. Modelling

28. EMEP models that simulate atmospheric transport, dispersion and chemistry processes to assess concentration and deposition levels under various emission and meteorological scenarios have been developed for several decades. They have achieved a high level of complexity and quality and have been made in full open access, facilitating transparency and openness of the modelling work that supports the Convention. EMEP also offers regular training courses on the use of the models, and model outputs are made openly available.

29. EuroDelta experiments (multimodel intercomparison experiments) held in the period 2010–2019, confirmed EMEP model quality. Such experiments typically involved up to 10 chemistry-transport models used in the State Parties alongside the MSC-W and MSC-E models. The scientific questions addressed by such experiments included model benchmarking in terms of performances for inorganic or organic secondary aerosols, analysis of air quality trends and specific topics such as benzo(a)pyrene (BaP) modelling at the European scale.

30. Country-scale case studies focused on detailed analysis of HM and POP pollution in selected EMEP countries (Belarus, Croatia, Czechia, France, Germany, Netherlands, Poland, Spain and United Kingdom of Great Britain and Northern Ireland) in close collaboration with national experts and involving detailed national data for both observations and emissions. Along with detailed information on country pollution, the studies made it possible to gain a new experience of pollution assessment with high detail. An added value of the country-scale studies is the possibility to evaluate and improve the EMEP modelling, tool, as well as national emissions data and the monitoring network.

31. In recent years, EMEP has developed a multiscale modelling system that bridges the scales from hemispheric down to urban (uEMEP) in a consistent way. This enables the assessment of the importance of transboundary pollution across all scales, including the urban scale.

32. A major strength of the Convention is the close collaboration between the effects community (WGE) and the air pollution modelling community. This has facilitated important developments on both sides. For instance, for vegetation, including crops, more biologically relevant flux-based critical levels for O_3 have been set. The work on exceedances of critical loads has also benefitted from close cooperation with respect to deposition to relevant land-use classes.

D. Hemispheric transport of air pollution

33. Following its 2004 and 2010 mandates (respectively, Executive body decisions 2004/4 and 2010/1), the Task Force on Hemispheric Transport of Air Pollution (TFHTAP) has built a community of experts working together to address the emissions, monitoring, modelling and impacts of O_3, aerosols, mercury (Hg) and POPs across regional to global scales. More than 1,000 experts from countries within the ECE region, including representatives from EMEP centres and task forces, and 29 countries outside the ECE, have participated in TFHTAP meetings or activities.

34. The publication *Hemispheric Transport of Air Pollution 2007: Air Pollution Studies No. 16*[12] contributed to the review of the 1999 Gothenburg Protocol. In 2010, *Hemispheric Transport of Air Pollution 2010: Air Pollution Studies Nos. 17–20*,[13] a 4-volume comprehensive review of the state of knowledge of intercontinental transport of O_3, fine

[12] United Nations publication, Sales No. E.08.II.E.5.
[13] New York, United Nations, 2010.

particles, Hg and POPs, was delivered. The policy-relevant findings of these experiments have been summarized for the review of the Gothenburg Protocol, as amended in 2012.

35. Important conclusions related to this part of the EMEP activity relate to:

(a) The sensitivity of seasonal and annual average O_3 levels in Europe to changes in emissions sources outside of Europe;

(b) Expected increases in global methane (CH_4) emissions that could offset benefits of additional controls of O_3 precursors within Europe and North America;

(c) Production and dissemination of a series of global emission mosaics. The mosaics consist of regional air pollutant inventories for Europe, Asia and North America consistently embedded in the European Commission Joint Research Centre Emissions Database for Global Atmospheric Research.[14]

E. Integrated assessment modelling

36. Cost effectiveness and economic benefits have gained increasing importance in the Convention since the 1994 Protocol on Further Reduction of Sulphur Emissions, in which the specification of Parties' emission reductions was made with respect to cost effectiveness. Key actors are the Task Force on Integrated Assessment Modelling and the Centre for Integrated Assessment Modelling, with results reported to EMEP/WGE and the Working Group on Strategies and Review. These actors also engage in outreach with local-scale decision-makers (Expert Panel on Clean Air in Cities), and information-sharing with experts from North America, eastern parts of the ECE region and globally.

37. Since 2010, the economic analysis and integrated assessment modelling performed in support to the Convention has undergone several advancements. The analysis supporting the Gothenburg Protocol, as amended in 2012, included both cost effectiveness analysis of reducing health effects and non-health effects, as well as cost-benefit analysis of policy proposals, covering improvements in a range of human health endpoints, crop production and reduced damages to buildings and materials. Operationally, the integrated assessment modelling is now made with higher geographical resolution, shows contributions from local, regional, national and international sources, and calculates emission control costs from the perspectives of social planners and the private sector. The assessment of economic benefits to society includes improved representation of human health, monetization of ecosystem effects, and forest growth.

F. Critical loads and dose-response relationships

38. Critical loads and dose-response relationships are used in collaboration with modelled air quality and deposition data to evaluate potential changes and trends in risk to vegetation, other biota and materials over different timescales. These relationships can also be used to predict recovery as pollutant load decreases. However, this is less precise due to potential lag effects within systems that can make the system respond more slowly than would be expected based on air quality alone.

39. ICP Vegetation has developed flux-based phytotoxic ozone dose (PODY) metrics and established a total of 21 flux-based O_3 critical levels, covering a range of crops, trees and semi-natural vegetation. It is recommended that these be used in risk assessments in preference to the concentration-based exposure index Accumulated Ozone exposure over a Threshold of 40 parts per billion (AOT40), because the flux-based metrics take into account how O_3 uptake is affected by climate, soil and plant factors, whereas AOT40 only accounts

[14] G. Janssens-Maenhout and others, "HTAP_v2.2: a mosaic of regional and global emission grid maps for 2008 and 2010 to study hemispheric transport of air pollution", *Atmospheric Chemistry and Physics*, vol. 15, No. 19 (October 2015).

for the atmospheric O_3 concentration above the leaf surface and could, therefore, be biologically less relevant.

40. ICP Materials has developed new dose-response functions for soiling. This includes functions for non-transparent materials quantified by the change in reflectance for white painted steel, white plastic and polycarbonate membrane. The dose-response set also includes functions for modern glass quantified by haze, particulate matter (PM_{10}) for all materials and sulfur dioxide (SO_2) and NO_2 for modern glass. Dose-response functions for corrosion have not been a recent update and are still valid.

41. ICP Modelling and Mapping has recently reviewed the empirical critical loads for N, last updated in 2010. With the participation of an exclusive network of scientists and experts, substantial new relevant information on the impacts of N on natural and semi-natural ecosystems has been incorporated into a report containing results of scientific studies (e.g., gradient studies on atmospheric N deposition).

42. Both modelled critical loads and critical loads based on empirical data of dose-response relationships are a robust means of assessing risks for biodiversity, by assessing eutrophication or acidification. Those processes cause changes in the soil properties and carry the risk that less resilient ecosystems may prevail, resulting in the loss of ecosystem diversity as an integral part of overall biodiversity. Also, the development of modelled critical loads in combination with vegetation models to assess shifts in vegetation and ecosystem integrity has progressed. Moreover, critical levels of O_3 include flux-effect relationships for flower numbers in grasslands, which can be used as an indicative risk assessment for potential impacts of O_3 on biodiversity.

G. Modelling critical loads and levels and risk assessment

43. The Manual for Modelling and Mapping Critical Loads and Levels[15] has been regularly reviewed and updated. This manual describes the scientific basis for the application of critical loads and levels and provides methods and harmonized indicators to assess the impacts of acidification, eutrophication, HMs, O_3 and PM on terrestrial and aquatic ecosystems, crops or building materials, respectively.

44. The Coordination Centre for Effects and the ICP Modelling and Mapping National Focal Centres regularly update the databases for risk assessment through critical loads for acidification and eutrophication. The identification of areas at risk using these critical loads and levels metrics is done based on concentration and deposition data that is provided through a fruitful collaboration with MSC-W. Risk assessment data have served as an important indicator for the assessment of the effectiveness of air pollution abatement strategies in and outside the Convention.

45. In January 2020, the Joint Expert Group on Dynamic Modelling was transformed into a designated international centre under ICP Modelling and Mapping. The new Centre for Dynamic Modelling (CDM) deals with dynamic modelling of ecosystem effects by acidification, HMs and nutrient N, including the interactions between climate change and air pollution, biological responses and terrestrial carbon sequestration.

H. Monitoring air pollution effects

46. Monitoring data are crucial for model development and validation in the Convention. The data have been used to understand the cause-effect relationship between air pollution and ecosystem effects and to evaluate predicted responses to cleaner air. Additionally, the ecosystem data have been used to evaluate combined effects of clean air and climate change, and effects of N on carbon sequestration.

47. The ICPs and centres have, through well-developed collaboration with national monitoring programmes, collected data on forests (including forest soils), crops and semi-natural vegetation, natural lakes and rivers, materials and cultural heritage and human health.

[15] See www.umweltbundesamt.de/en/manual-for-modelling-mapping-critical-loads-levels.

This has enabled the development of extensive databases on the effects of air pollution on ecosystem vitality, diversity and productivity, corrosion of materials and human health on the basis of effects of air pollution based on monitoring networks in natural/remote, agricultural and urban sites in Europe and North America. The extensive monitoring by ICPs is based on detailed manuals for monitoring air pollution impacts on terrestrial and aquatic ecosystems, which allow harmonization of the monitoring across WGE and Parties. This has also been used for purposes outside the Convention, for instance, in European Union research and directives and other monitoring networks in Europe (e.g., the Long-term Ecosystem Research Network in Europe) and beyond (e.g., the Acid Deposition Monitoring Network in East Asia).

48. Long-term monitoring under WGE has provided scientific evidence that the measures taken to reduce air pollution have their intended effect, i.e. ecosystem recovery, reduced corrosion of materials and reduced burden of disease. Many lakes, rivers and catchments have recovered from acidification, although some areas remain acidified, with slow recovery. In intensive monitoring sites, the interaction between air pollution and climate change, as well as the effects on forests, soil, and water have been observed, and a greater understanding of these complex relationships has been gained.

I. Improving knowledge about health effects

49. The Joint World Health Organization (WHO)/Convention Task Force on Health Aspects of Air Pollution brings together environmental and public health experts representing Parties to the Convention. In 2012, the report *Health effects of black carbon*[16] was published. Studies of short-term health effects suggested that BC is a better indicator of harmful particulate substances from combustion sources (especially traffic) than undifferentiated particulate matter (PM) mass, but the evidence for the relative strength of association from long-term studies was inconclusive. The studies *Health Risks of Air Pollution in Europe – HRAPIE Project: Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide*[17] and *Review of Evidence on Health Aspects of Air Pollution – REVIHAAP Project*[18] were published by the WHO Regional Office for Europe (WHO/Europe) in 2013, providing a set of response functions that have been widely applied in integrated assessment and cost-benefit modelling under the Convention ever since.

50. In 2015, WHO/Europe presented the report *Residential heating with wood and coal: health effects and policy options in Europe and North America*,[19] which summarized the evidence linking emissions from heating with wood and coal to serious health effects, such as respiratory and cardiovascular mortality and morbidity. Each year, an estimated 61,000 premature deaths are attributable to ambient air pollution from residential heating with wood and coal in Europe, with an additional 10,000 deaths in North America. The report concluded that there was a need to address wood biomass heating as a major source of harmful air pollutants, especially PM.

51. In 2021, WHO/Europe published *Human health effects of polycyclic aromatic hydrocarbons as ambient air pollutants: Report of the Working Group on Polycyclic Aromatic Hydrocarbons of the Joint Task Force on the Health Aspects of Air Pollution*,[20] which presents evidence suggesting increased cancer incidence in relation to polycyclic aromatic hydrocarbons (PAHs) in ambient air, as well as positive associations between ambient PAHs and breast cancer, childhood cancers and lung cancer. The report concludes that, for several PAHs that are carcinogenic air pollutants, a lowest possible exposure should be aimed at to minimize the risk of cancer development.

[16] Nicole A.H. Janssen and others (Copenhagen, World Health Organization Regional Office for Europe (WHO/Europe), 2012).
[17] Copenhagen.
[18] Copenhagen.
[19] Copenhagen.
[20] Copenhagen.

52. The new landmark publication *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide* was published by WHO in 2021,[21] providing quantitative health-based evidence-informed recommendations for air quality management, expressed as long- or short-term concentrations for several key air pollutants. The new WHO guidelines provide air quality guidelines levels of $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, and carbon monoxide (CO), and interim targets, as well as good practice statements about several types of PM, such as black/elemental carbon, ultrafine particles, and sand and dust storms.

III. Strategic priorities for the scientific work under the Convention to address remaining challenges

A. Improving scientific knowledge for improving effectiveness of control strategies

53. The 2016 assessment report[22] shows that there has been significant progress in reducing emissions, with benefit to health, ecosystems and materials over the last 20 years. However, significant impacts remain and there is an urgent need to improve knowledge in some areas to increase the efficiency of control strategies. They relate to emerging pollutants, as well as to understanding of complex processes that drive atmospheric and dynamic chemistry and health and environmental effect pathways.

54. Understanding trends in pollutant levels: In the period 2000–2021, levels of air pollutants underwent different decreasing trends, with changed trends in the period 2010–2021 as compared with the period 2000–2010. In particular, ambient levels of $PM_{2.5}$ and PM_{10} drastically decreased in the period 2000–2010 (close to 40–50 per cent), but since 2010, in many countries, levels remained constant. For O_3, a major flat trend has been reported for regional background peak values, while in a large proportion of cities, urban background O_3 levels increased, especially in the period 2000–2010, probably as a consequence of the decrease of O_3 titration by nitrogen oxide and changes in O_3 formation regimes of most cities in Europe. The analysis of the 2010–2019 (and beyond) trend will be a major focus since levels of several pollutants are very distant from the new respective WHO air quality guidelines, and accordingly, additional efforts in reducing pollutants should be foreseen.

55. **Ozone**: Since 2005, peak O_3 concentrations have fallen, while urban background levels have tended to increase. Modelling of O_3 concentrations to inform policy analysis is very complex given that it is influenced by a wide range of anthropogenic and biogenic precursors, by emissions at all scales from local to hemispheric, and by meteorological conditions. Moreover, better understanding of the interlinkages between emission of precursors, O_3 formation in the atmosphere, climate change and O_3 effects on vegetation is needed. In particular, the role of volatile organic compounds (VOCs) in emissions and ambient air, and the implication for vegetation, must be further investigated. The contribution of CH_4 emissions to ozone formation from the local to the global scale must also be better characterized to avoid situations where CH_4 emissions offset benefits of additional controls of O_3 precursors within Europe and North America.

56. **PM**: In countries where PM concentrations decreased significantly over the past years, atmospheric $PM_{2.5}$ and PM_{10} are nowadays dominated by the secondary PM fraction. Furthermore, the reduction of nitrogen oxides (NOx) and SO_2 emissions in the last decades accounted for an increase in the relative contributions of secondary organic aerosol (SOA), both from anthropogenic and biogenic sources. Understanding secondary PM mechanisms is a very complex task and is highly influenced by meteorology, but it is essential to carry out sensitivity analyses of specific policies and develop objective assessment of the impact of main sources and control strategies.

[21] Geneva.

[22] Rob Mass and Peringe Grennfelt, eds., *Towards Cleaner Air: Scientific Assessment Report* (Oslo, United Nations Economic Commission for Europe (ECE), 2016)

57. **Improving the understanding of the condensable fraction of organic PM**: Condensable primary organic aerosol emissions are a class of organic compounds that are in the vapour phase at the point of exhaust emissions, but that undergo both condensation and evaporation processes as the stack air is cooled and diluted upon discharge into ambient air. Emission factors measured in or close to the high-temperature high-concentration exhaust stack or pipe may underestimate the amount of PM or gas that actually enters the atmosphere, depending on the filters, dilution and sampling conditions of the emission measurement:

(a) In the current emission reporting to EMEP/the Convention, there is no clear definition of whether condensable organics are included or not, and, if included, to what extent. Thus, for the same activity (e.g., burning one unit of wood in a particular appliance type) very different PM emission factors can be found in national reporting from different countries;

(b) Estimation and measurements of emission factors with condensable (for which no standard holds currently in Europe) is a part of the question; evaluation of activity data (fuel use, types and ages of appliances, description of use and practices) is the other challenge.

58. **Ammonia**: Ammonia emissions play an increasingly important role for eutrophication and acidification, and are important for secondary inorganic PM formation. However, only modest reductions of ammonia have been achieved since 2000 compared to the other pollutants. Therefore, ammonia's relative contribution to air pollution and its effects will become increasingly important. Thus, in addition to improving/revising critical levels and loads assessment, improved assessment of ammonia effects and linking of air quality and biodiversity monitoring are needed.

59. **Polycyclic aromatic hydrocarbons (PAHs), including BaP and other POPs**: Despite the application of several restrictive measures regarding PAHs in recent decades, emissions of PAHs remain a concern:

(a) Current limitations for understanding and evaluation of PAH long-range transport, fate and trends include uncertainties of current emission inventories, insufficient knowledge of the effects of photochemistry and heterogeneous reactions of PAHs, and their interaction with organic matter, BC and SOAs, under different environmental conditions;

(b) Efforts to continue the identification of new POP-like contaminants, as well as analysis of their fate in the different environmental compartments and adverse effects on human health and ecosystems, are needed.

60. **Secondary emissions (HMs and POPs):** An important peculiarity of HM and POP cycling in the environment is their accumulation in the environmental media (soil, vegetation, water, sediments) with possibility of reemission to the atmosphere. These secondary emissions can significantly affect contemporary pollution levels in the Convention Parties. Besides, due to longer residence time of the pollutants in the terrestrial and aquatic media, secondary emissions postpone the effect of emissions reduction on pollution changes, as well as on human and ecosystem exposure. Current understanding of HM and POP secondary emissions is limited, and further improvement of the knowledge is needed. An update of the state of knowledge on critical limits and critical loads of HMs and their exceedance is required.

61. **Chemicals of emerging concern (CECs: microplastics, polyfluoroalkyl substances (PFAS))**: Pollution assessment of CECs presents significant challenges due to insufficient knowledge of their sources, transport and fate in the environment. In particular, more data are needed on their concentrations in different environmental media over wider geographical areas and wider periods of time, on physical-chemical properties, and on their releases to environmental compartments. For example, interaction between atmospheric microplastics and toxic chemicals, ecosystems and human exposure should be better understood. Preparatory work to explore long-range transport potential of microplastic as a carrier of toxic HMs and POPs/CECs is of importance (e.g., monitoring of levels of microplastics, collection of information on emission sources, physical/chemical properties, development of modelling approaches). Further links to chemical regulators are necessary.

62. **Corrosion and soiling:** Progress to improve risk assessment for materials will require: an update of dose-response functions for corrosion and soiling for an efficient use in

scenario calculations and to enable more accurate quantification of the effect of PM; the development of methodologies for assessment of corrosion and soiling of materials for more accurate quantification of seasonal effects; increased geographical resolution to better quantify effect at United Nations Educational, Scientific and Cultural Organization (UNESCO) cultural heritage sites; and the upscaling of economic assessments of materials and cultural heritage to a scale relevant for the Convention.

63. **Biodiversity:** The existing approaches for estimating critical loads and levels have proven to be a highly valuable tool for assessing the threat of airborne pollutants to biodiversity in natural and semi-natural ecosystems. Additional efforts are needed to further develop the critical load methodology by incorporating insights derived from modelling shifts in plant species composition. In addition, impacts on ecosystem services could be progressively incorporated into risk assessments.

64. **Biological recovery**: Further work is needed in assessing trends and factors that affect biological recovery in aquatic and forest ecosystems, including climate change, land use and the fate of accumulated N. It will be important to define both the reference state (also in the light of climate change) and suitable indicators for monitoring changes in biodiversity.

65. **Forests, air pollution and climate change:** Climate change will be an important influence on the functioning of forest ecosystems in the near future and links between air pollution and climate change will need to be further investigated in the next decade. Although some studies have been already carried out on the basis of, for example, ICP Forests data, actions are needed to further explore air pollution-related cause-effect relationships, with special emphasis on the combined effects with drought and warming, and to provide ground truth of remote-sensing indicators.

66. **Non-forest vegetation, air pollution and climate change**: There is a need to further investigate the modifying influence of climate factors, and interactions via elevated N and CO_2, on O_3 effects on plants and to consider how these effects should be factored into future risk assessments. N and O_3 both individually affect plant biodiversity, but the interactive effect requires further investigation. This is particularly pertinent as exposure to high O_3 and high N deposition can co-occur. In addition, in future climates, O_3 uptake to vegetation could be altered even in the absence of changes to emissions/O_3 concentrations.

67. **Marine protection:** A first study using a pragmatic approach to assess the risk of eutrophication through atmospheric N deposition was conducted by the Ad hoc Group on Marine Protection under the Convention, in cooperation with experts from the Baltic Marine Environment Protection Commission (HELCOM).[23] It concluded that there is widespread, albeit relatively low, exceedance of critical atmospheric inputs, an analogue to critical loads. The study so far focused on the open Baltic Sea, whereas the most sensitive areas with respect to eutrophication are the coastal zones. Their inclusion in future work is therefore needed. Also, the cost-effectiveness of control options for each input category, including aquatic sources, should be considered for reduction strategies in future.

68. **Health impacts of air pollutants:** The recommendations of the HRAPIE project on response functions for mortality and morbidity need to be updated, particularly to recognize the work on mortality carried out in revision of the WHO air quality guidelines and to consider evidence on various chronic health conditions (stroke, diabetes, etc.) that has emerged in the literature in the interim. Further investigation is needed of multipollutant models to reduce the risk of double counting impacts, especially between $PM_{2.5}$ and NO_2. The literature on differential toxicity of particle species, and health risks of toxic metals, POPs and CECs needs to be kept under review. Consideration must be given to the effect of health inequalities on the risks of air pollutants.

[23] "Options to consider marine eutrophication in the review of the Gothenburg Protocol", informal document under agenda item No. 7, available at https://unece.org/environmental-policy/events/seventh-joint-session-emep-steering-body-and-working-group-effects.

B. Improving emission data

69. Updating the EMEP/EEA Guidebook: The Guidebook is updated every three to four years in order to capture the latest scientific knowledge and provide the most up-to-date methodologies for estimating air quality pollutant emissions. This work needs to continue through the period of the long-term science plan. The long-term funding of work on the Guidebook needs to be resolved: it is not currently funded by EMEP, although it is a key output of work under the Convention. This is a barrier to the delivery of priority improvements and for wider updates.

70. Strengthening the links between the source measurement, emissions inventory, ambient concentrations measurement and modelling communities: Experience gained by the emission inventory community highlighted the need to develop scientific cooperation with measurement experts and to consider for the Guidebook update results from source measurement campaigns carried out in the countries. There are also benefits from improving the link between the emissions inventory community and the users of its data, especially the modellers, who can play a prescriptive role in the overall improvement of the emission inventory framework and tools.

71. Annual in-depth review of emission inventories: The in-depth review was previously established on a rota system, meaning that an individual Party would be reviewed approximately every five years. However, recent developments that aim at updating allow more flexibility of the review. They include the possibility to increase the frequency of the in-depth reviews where significant quality issues are found and to perform an ad hoc review to focus on specific aspects of inventory data quality or science (spatial distribution, specific sectors, etc.). This allows the review process to support the Parties in making improvements that are the highest priority. For example, in 2022, the review focuses on the condensable component of PM emissions in the residential and transport sectors. Suggestions for future review topics include gridded data and institutional arrangements.

72. Improving knowledge for some source categories, pollutants, and their fate: the following priorities have been identified:

(a) Domestic, residential and commercial sources of PM and precursors remain a major contributor to PM matter pollution and should be further documented (see also para. 57 above on condensables in PM);

(b) PM speciation (condensable, carbonaceous aerosols, inorganic compounds, etc.) and CH_4 are important issues highlighted by the Gothenburg Protocol review process;

(c) POPs and HMs as parts of PM (need for consistent methodologies between various compounds); speciation of Hg and congener composition of POPs. Such emissions are not reported but remain critical for modelling;

(d) Non-exhaust vehicle contributions have increased because exhaust contributions have been significantly reduced by current European policies (e.g., EURO standards). Furthermore, the increase in weight of e-vehicles might increase road dust and vehicle wear emissions;

(e) Non-methane volatile organic compounds (NMVOCs) speciation, including update of sectoral emission profiles with respect to the country activities. For instance, with new EURO standards, VOC emissions from petrol cars will increase (compare to diesel cars) because of evaporative VOC emissions and higher exhaust emissions;

(f) Biogenic/natural emissions (nitrogen oxide, VOC (including speciation), dust - bare ground resuspension): as anthropogenic emissions in Europe have been declining substantially in the last decades, natural emissions are gradually playing a more important role. There is a need for a review of the methods used for quantification and parametrization of these sources, including their transport and removal patterns. Furthermore, new sources of observational data, such as satellite data and the EMEP VOC campaign, should be used to better understand and quantify these sources;

(g) Currently, the data reported by the Parties on international shipping are insufficiently consistent to be used for the gridded data set and should be improved in a centralized way;

(h) Temporal variability: there is need to review approaches since it is a very sensitive parameter for air quality modelling.

73. Emission verification: new means and methodologies to support emission verification processes (inverse modelling, satellite observations, modelling) are available and should be further discussed between the emission and modelling communities.

74. Linking the scales: to support multiscale modelling systems implemented by the EMEP centres, multiscale emissions systems should also be developed. Ensuring consistency between scales is a real challenge and requires specific approaches. Lastly, reducing uncertainties in gridded emission data sets, whatever the targeted domain (regional or global), is a recurrent objective of emission work.

C. Improving monitoring and modelling

75. Expanding the EMEP monitoring network: The greatest challenge in the air pollution monitoring programme is poor spatial coverage throughout the ECE region, particularly in the EECCA region and South-Eastern Europe. Spatial coverage varies by components and topics. There is a need for more sites with VOC speciation (relevant for O_3 and SOA) and chemical speciation of aerosols. Also, cooperation with air quality networks, especially regarding monitoring of O_3 and PM precursors, as well as observations of aerosol properties in urban and industrial areas, should be increased. There is also a lack of observations for several legacy POPs, and growing concern regarding potential harm from new or emerging contaminants, for example, substitutes for regulated POPs. It is necessary to develop monitoring strategies for these compounds.

76. Strengthening EMEP network capacities: The monitoring programme benefits from increased use of observations from monitoring outside the regular EMEP network, i.e. from remote sensing, microsensors, and intensive measurement campaigns, including supersites in urban areas. To ensure that observation data are of known quality and adequate for their intended use, EMEP will maintain and strengthen collaboration with the Global Atmosphere Watch Programme of the World Meteorological Organization (WMO) and European central quality assurance facilities set up by research infrastructures (e.g., ACTRIS). Timeliness in the whole chain of data flow, from reporting to open access, should be further improved, and data services should be developed to serve multiple clients and needs.

77. Setting intensive observation periods to target specific topics: Conducting targeted measurement campaigns aimed at specific processes governing HM and POP fate and transport would facilitate improvement of air quality models (e.g., measurements of Hg chemical species, gaseous and particulate POP phases, composition of complex POP mixtures, co-located measurements of POPs and aerosol composition).

78. Ecosystems monitoring: The long-term ecosystems monitoring of WGE is an unprecedent, valuable resource for model development and validation in the Convention. However, the monitoring network should be improved by extending it to areas not currently well covered (especially in the EECCA region), with the participation of all Parties to the Convention, the inclusion of a broader range of ecosystem types, and the development of specific monitoring methodologies for these ecosystem types. This will provide data to detect recovery, assess efficiency and sufficiency of control measures and identify new impacts. ICP Integrated Monitoring has developed methodologies and protocols towards the inclusion of terrestrial, non-forest ecosystems.

79. Biomonitoring: Measurements of HMs, N and POPs in mosses and other biomonitoring techniques can complement available EMEP monitoring data, especially in regions where the EMEP monitoring data are not available. It is recommended to continue regular moss surveys in the EMEP region under ICP Vegetation supervision.

80. Monitoring data access: monitoring networks should improve access to data for all potential users, and enable closer cooperation and coordination with other monitoring networks initiated by other policy frameworks, such as that under the European Union National Emission reduction Commitments Directive.[24] The Convention should take every opportunity to make monitoring networks serve multiple users (national and international) and other environmental issues such as climate, biodiversity and land-use management.

81. Challenges in modelling O_3, VOC and secondary aerosol chemistry: Despite large reductions in NOx and NMVOC emissions during the last decades, exceedances of air quality guidelines and critical levels for O_3 remain a problem. Several issues deserve to be considered in the upcoming years:

(a) In general, regional air quality models tend to underestimate peak values of O_3 during summer, although the reasons behind this are not fully understood. It has been hypothesized that this could be related to biogenic or anthropogenic VOC emissions, CH_4 and/or photochemistry, which are potentially not well parametrized in the model. Soil NOx emissions might also play a role;

(b) Residential heating emissions are major sources of so-called semi volatile organic compounds (SVOCs) – important precursors of organic aerosols in Europe, especially in winter. Although progress has been made within EMEP as to how such emissions could be included in emission reporting, large uncertainties remain regarding the activity data, emission factors, etc.;

(c) Another class of compounds, intermediate volatile organic compounds (IVOCs), are probably partly lacking from the reporting of VOC and/or PM, and are expected to be significant for the industrial, traffic, solvent and domestic sectors. Similarly to condensable organic matter, IVOCs are important precursors of organic aerosols. Understanding of the SOA formation process (e.g., from SVOCs or IVOCs) has evolved during the last decade(s), and organic aerosol chemistry schemes are continually being improved. However, large uncertainties still remain regarding the modelling of these compounds.

82. Gas/particle partitioning for POPs and Hg chemistry and air surface changes: Atmospheric chemistry and gas-particle partitioning play an important role in long-range transport and deposition of Hg and POPs, influencing dispersion distance and seasonality of pollution levels. Current understanding of chemical and physical mechanisms responsible for transformations of Hg compounds, POP degradation and interaction with atmospheric aerosol is incomplete. Further studies of particular processes and development of new model parameterizations are needed to improve assessment of current pollution levels and future projections.

83. Deposition parameterizations (including dry deposition of N species): N and sulfur are deposited either through wet deposition or dry deposition. Dry deposition is also a very important atmospheric sink of tropospheric O_3. From a modelling perspective, the dry deposition process is especially challenging, as there are scant data available for performing evaluation of the modelling parametrizations or results. Dry deposition parameterizations are complex, and multimodel evaluation of parameterizations in different models reveals a large diversity in results.

84. Global scale modelling: Technical challenges for improved global simulations of ground-level O_3 for the ECE region include: more accurate simulation of the global CH_4 lifetime; better resolution of marine shipping emissions and the NOx chemistry of ship exhaust plumes; better representation of vertical mixing of O_3 from the free troposphere into the planetary boundary layer; and better representation of O_3 deposition to vegetation.

85. Linking the scales: local air pollution, including in cities, is heavily influenced by long-range and transboundary transport of pollutants. Furthermore, urban pollution interacts with, and influences, the air pollution background. Therefore, further development of a consistent approach linking multiple scales is needed, including both downscale and upscale

[24] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.344.01.0001.01.ENG&toc=OJ:L:2016:344:TOC.

interactions. Although, in principle, multiscale modelling (from hemispheric to urban scale) calculations can be performed with the Conventions tools, the accuracy of such results relies on the underlying data, especially emissions, but also on consistent coupling between the various models (including, in particular, the choice of scenarios and timescales to be explored).

86. Resuspension of HMs due to air pollution and climate change and mobilization for ecosystems: Secondary emissions, including resuspension of particle-bound HMs and air surface exchange of Hg and POPs, depend on various factors, including: historical deposition and accumulation; meteorological and surface conditions; and physical and chemical processes in the environmental media. Correct estimates of these emission sources and their contribution to pollution levels and trends in the EMEP region requires further development and evaluation of model parameterizations of the air-surface exchange processes and the multimedia modelling approach.

87. Transport pathways and consequences of changing climate: In the next decades, air pollution will be influenced by, and have an impact on, climate variability and change. Climate change influences the meteorological drivers of air pollution such as stagnation episodes or heatwaves, therefore having an impact on the accumulation of air pollutants, or their photochemical formation. However, climate change also largely influences emissions of biogenic or natural precursors of air pollutants, such as VOCs, or resuspension of mineral dust induced by land-use changes. Consequently, climate change might generate a need for additional emission controls to achieve air quality targets in Europe. Besides, several air pollutants also have a radiative effect; this is particularly the case for O_3 and aerosols, the precursors of which are therefore referred to as short-lived climate forcers. There is a need to further investigate these interactions between climate and air pollution.

88. Better use of data assimilation/data fusion methods to assess exposure studies: Extend the use of data assimilation techniques and/or data fusion methods, combining the use of remote sensing observations (from satellites) and in situ observations for reanalysis purposes when they result in a significant improvement in the accuracy of the technical basis for the policy discussion, for instance, exposure assessments or exceedances of critical loads. Such correction of the models on the basis of observations only applies to past or recent time periods, but there are prospective methods on how to best convey these corrections in the prospective scenarios that constitute a cornerstone of the modelling work undertaken under the Convention.

89. Dynamic modelling: In order to better understand timescales and time lags of ecosystem responses to changes in air pollution, further work will be required on modelling the dynamics of the ecosystems over time, including biodiversity, interactions of air pollution with climate change and the management of cropland, grassland and forests.

90. Marine issues: N pollution, toxic HMs and POPs, as well as various CECs, have a negative impact on marine ecosystems. To quantify atmospheric input of pollution and trends of contamination of marginal seas in the EMEP region, further research activities in cooperation with the marine conventions (e.g., HELCOM, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)) will be investigated.

D. Linking science to policy: integrated assessment modelling

91. Increasing synergies between Convention protocols (Gothenburg Protocol and Protocol on POPs), with other policy areas (climate/energy/food), at the international and local levels, to ensure consideration of co-benefits and trade-offs. The need for high-level engagement needs to be recognized and funding is required for collaborative research and developing long-term scenarios including carbon neutrality, circular economy, dietary change, N management, as well as the impact of high energy prices.

92. Inclusion of behavioural measures to meet WHO air quality guidelines and critical loads for N: This requires investigation of effective policy tools to stimulate behavioural change and means of including them in control strategies. An inventory of success stories would make a useful starting point, considering, for example, recent dietary change in society

and changes in energy consumption. Quantifying welfare effects of behavioural change is another element for consideration.

93. Linking the scales in integrated assessment modelling: echoing the atmospheric modelling priorities, extending the GAINS model to enable assessment of the cost-effectiveness of additional local and hemispheric measures to reduce O_3 and PM levels in the ECE region. At the local scale, work will continue with the Expert Panel on Clean Air in Cities to develop nested control strategies. At the global scale, linking the scale also means taking into account the questions of CH_4 control strategies and the evaluation of the impacts and cost effectiveness of global and regional CH_4 measures to reduce O_3 levels in the ECE region.

94. Developing new methodologies for socioeconomic impacts: Increasing completeness of cost and benefits assessments and developing a systematic approach to uncertainty and sensitivity analyses to make policy advice more robust in future scenarios, epidemiology, and non-linear atmospheric processes will be essential. Use of updated tools and database will support such developments.

95. Consideration of inequalities: Needs to be factored into analysis of exposure, cost of emission reductions, and benefits of reductions, including urban/rural aspects. A focus on the most polluted cities could form a new incentive for international cooperation on air pollution and help to overcome current barriers to ratification of protocols. Methodologies based on equity weights can be tested.

96. Characterizing uncertainties to inform policy development: A systematic and comprehensive approach to dealing with uncertainty is currently lacking. Development of such an approach is essential to make policy advice more robust. This should account for the full range of uncertainties through the various stages of analysis from quantification of emissions to estimation of control costs and benefits. It should include consideration of uncertainties at different scales down to local assessments. The economic cost and benefit assessments of cleaner air are incomplete, biasing the current cost-benefit analysis to underestimate the socioeconomic benefits of cleaner air.

IV. Partnership in and outside the Convention

97. Partnership between the Convention science bodies and the national programmes of the Parties is the historical backbone of the Convention and must be maintained.

98. Interactions with European Union policy and research programmes remain of high importance and of mutual benefit. In addition, revision, development and implementation of European Union air legislation is supported by the knowledge and tools developed for the Convention’s needs. One very recent example of such cooperation relates to support provided by WGE for the implementation of reporting obligations related to the impacts of air pollution on ecosystems in the European Union National Emission reduction Commitments Directive.

99. Both Canada and the United States of America are Parties to the Convention and to several of its protocols, including the 1984 Protocol on Long-term Financing of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe. There is a long tradition of cooperation between EMEP and North American scientists. Much of the work related to global O_3, POPs and HMs, including the transport of these pollutants to Arctic regions, has been conducted jointly.

100. The Convention needs to develop a common understanding of how issues related to air pollution and its long-range transmission are of relevance to other initiatives, such as the Intergovernmental Panel on Climate Change; the Convention on Biological Diversity; the Stockholm Convention on Persistent Organic Pollutants; the Minamata Convention on Mercury; the United Nations Environment Programme; and the European Union Copernicus initiative. It is important to show how the focus and the capacity built within the Convention science bodies can be beneficial in dealing with these political issues and developed as driving forces at the Convention level.

101. Joint work with the relevant international initiatives should continue. For example, to:

(a) Continue supporting the development of formal links between the Convention and the Malé Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effects for South Asia, and the Acid Deposition Monitoring Network in East Asia;

(b) Further develop emission inventory capacities through interaction with the Global Emissions InitiAtive and the Emissions Database for Global Atmospheric Research of the European Union Joint Research Centre;

(c) Establish links to the ecosystem (terrestrial, as well as marine) – atmosphere communities, for example, OSPAR and HELCOM;

(d) Further develop collaborations with the Arctic Monitoring and Assessment Programme, particularly in the framework of activities related to BC and CH_4;

(e) Continue to collaborate with the Minamata Convention on Mercury and the Stockholm Convention on Persistent Organic Pollutants, contributing to the various assessment initiatives performed thereunder;

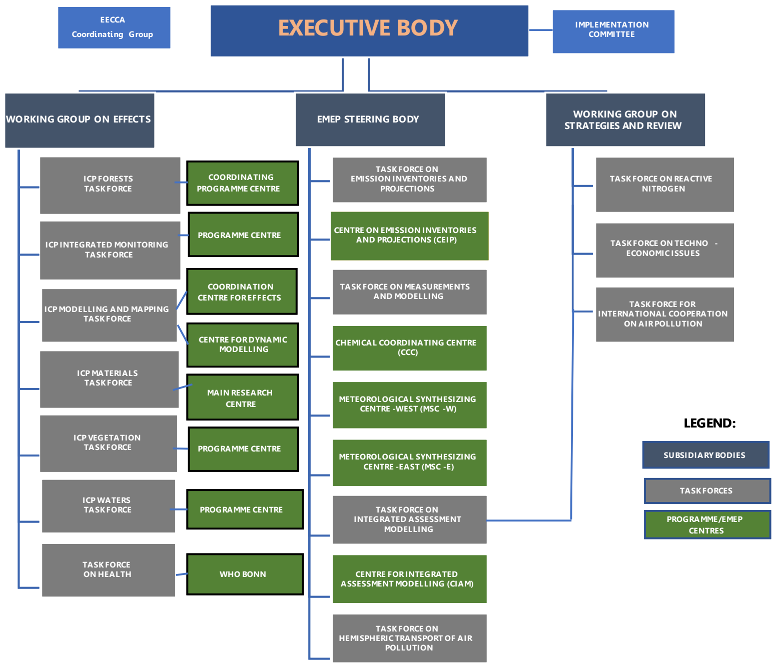
(f) Carry out work with the WMO Global Atmosphere Watch in its implementation of a common approach to issues related to air pollution, its long-range transmission and the interaction with climate change;

(g) Develop joint work with the European Union Copernicus Atmosphere Monitoring Services based on exchange of data, tools and mutual assessments.

102. Beyond partnership, outreach initiatives include communication about the Convention work and dissemination of its science results. Increasing visibility of the Convention and its science bodies is essential to support the Convention's long-term strategy, stimulate actions to deal with remaining challenges and share knowledge and tools developed by the Convention with non-ECE Parties.

Annex

Organizational chart of the Convention



Abbreviations: EECCA, Eastern Europe, the Caucasus and Central Asia; EMEP, Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe; ICP, international cooperative programme.